APPLICATION OF THE
SEQUENTIAL UNCONSTRAINED MINIMIZATION
TECHNIQUE IN A
SYSTEMATIC CONTAINERSHIP DESIGN

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by

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ABSTRACT

This paper investigates the preliminary ship design process. The thesis begins by looking at methodologies for ship design and concludes that a different outlook on the overall process could provide an improvement. In particular, possible modifications were identified in the owner's requirements as traditionally given to the designer. After the new design procedure was developed, effort shifted to implementing the procedure for a containership design.

A preliminary ship design model is developed. This model was then used in a test design problem in which an owner desires a single ship to add to an existing trade route. The design model was used to identify acceptable ship alternatives.

The determination of attractive designs was accomplished by a version of an optimization method known as a Sequential Unconstrained Minimization Technique. This method employs a barrier penalty function to handle the problem constraints. The search method was found to be effective in identifying design alternatives. In particular, it behaved well with the discontinuities imposed by the discrete engine selections involved with gas turbine power plants.

Thesis Supervisor: Thomas L. Magnanti
Title: Assistant Professor

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INTRODUCTION

Through the years, ocean transport systems have provided a common forum in which the businessmen and engineers could participate as a team. The complexity of the present systems as well as the sophistication of their design has not evolved without numerous growing pains. Over the years, society has developed the framework in which each party operates. The boundaries of responsibility for the two are not always well defined nor are their liabilities. This vagueness extends to their interaction with the rest of society. The results of past efforts to formalize their rules with respect to the ship design process can be found in rules of the American Board of Shipping and of many insurance companies. These rules guide the engineer/designer in his task so that the final ship design will meet certain minimum standards. These standards have been developed over the years and are based on experience.

This paper does not propose a change in the traditional roles of the businessman and the engineer as related to ocean transport systems, nor does it develop any new innovations into either of their professional areas. It does, however, attempt to define explicitly the formal relationships between the parties involved in the design process and to indicate how these relationships can be used in actual

ship design. The approach taken is not traditional. The result is not a new relationship, but rather a more defined and process oriented approach where there can be a better agreement as to each parties role with the result of improving their joint effort.

In an attempt to demonstrate this philosophy, the thesis presents a sample problem. With this problem, a method of solution is then pursued. The important aspects of this problem are identified in the context developed earlier in the paper which defines the roles of the participants. The problem is approached in an objective manner and the outputs are identified which would prove useful to a decision maker. The paper presents the results with caution. First, because the solution addresses only the problem outlined in the scenario. Secondly, the design model has not yet been verified by present design practice. Finally, the optimization method may not in itself identify the overall best alternative to a real life problem. For this reason, no attempt is made to identify such a result.

One of the easiest ways to present a problem is to relate a scenario. From this, the assumptions and simplifications made in the analysis become more palatable and the solution is not regarded as simply a mass of assumptions presented for the convenience of the solution technique. The

scenario also identifies a clearer division of roles of the businessman (referred to as the customer) and the engineer (referred to as the designer) in the scenario. By restricting the problem as stated in the scenario, the real life complications and ambiguities are minimized. However, these will not be ignored in the development of the design process. The information flows of the design methodology guided the development of the design program. This program utilized the capabilities of the computer and the solution technique. Before the design methodology is outlined or the scenario developed, it is important to identify the approach of the paper.

This paper uses a systems analysis format for presentation. By this it is meant that the first issues covered involve the problem definition and objectives of the study. Following the problem definition, the paper proceeds to identify criteria and measures of effectiveness for the problem solution. This is then followed by an outline of the different types of alternatives available. From this position, a decision model is developed. Tools known as optimization techniques are applied to this model. The results and the analysis are accomplished by the application of a Sequential Unconstrained Minimization Technique referred to as SUMT. The results are then studied and presented so that a decision can be made. This decision may

not cover the problems originally raised in the scenario, but should at least pave the way for the next design iteration. As such, the paper demonstrates the computer's capabilities. This, in turn, will demonstrate the possible role of a computer in a computer aided design.

Definitions are imperative for a proper understanding of any study. A list of model variables have been collected with their definition in Table 14 found in Appendix A. Their use in context should not prove difficult for the reader. There is one definition, however, that deserves explanation before we begin. This relates to the use of the terms 'closed form' or 'explicit' as qualifiers of expressions in the mathematical model. These will be used interchangeably in the paper. By an explicit expression, it is meant that the relationships between the variables involved can be found in terms of an algebraic expression. In particular, we will be interested in the relationships involving the decision variables.

The complexity of real life design problems made it difficult to identify and assess all the implications of the proposed design methodology. The results of the design model were useful in identifying the usefulness in a container ship design. This paper should serve as a basis from which to reanalyze the existing methods used in the design of ship systems.

CHAPTER I.

OCEAN TRANSPORTATION SYSTEMS

Much has been written about transportation systems. The important features of any transportation system are its collection, warehousing, transport and distribution subsystems as well as the associated management and human subsystems. In today's economy, some transportation systems are so large that neither a single individual nor a single corporation can control and direct the action of all the elements. This is especially true of the ocean transportation systems. We will limit our discussion to the actual transport by the ocean vehicle. The character of this ocean transport subsystem which distinguishes it from other modes of travel is the need to have a transporting vessel capable of transisting an ocean. In this transit, a ship will experience a hostile environment. The advantage of ocean transport as opposed to other transport methods is the ability of an ocean transport system to carry larger loads, either in bulk or weight.

1.1 Elements

From the following figure, the ocean transportation system can be divided into three basic parts. The first is the mode of ocean transport by ship. At each end of the ocean transport is a port and terminal system. At these terminal

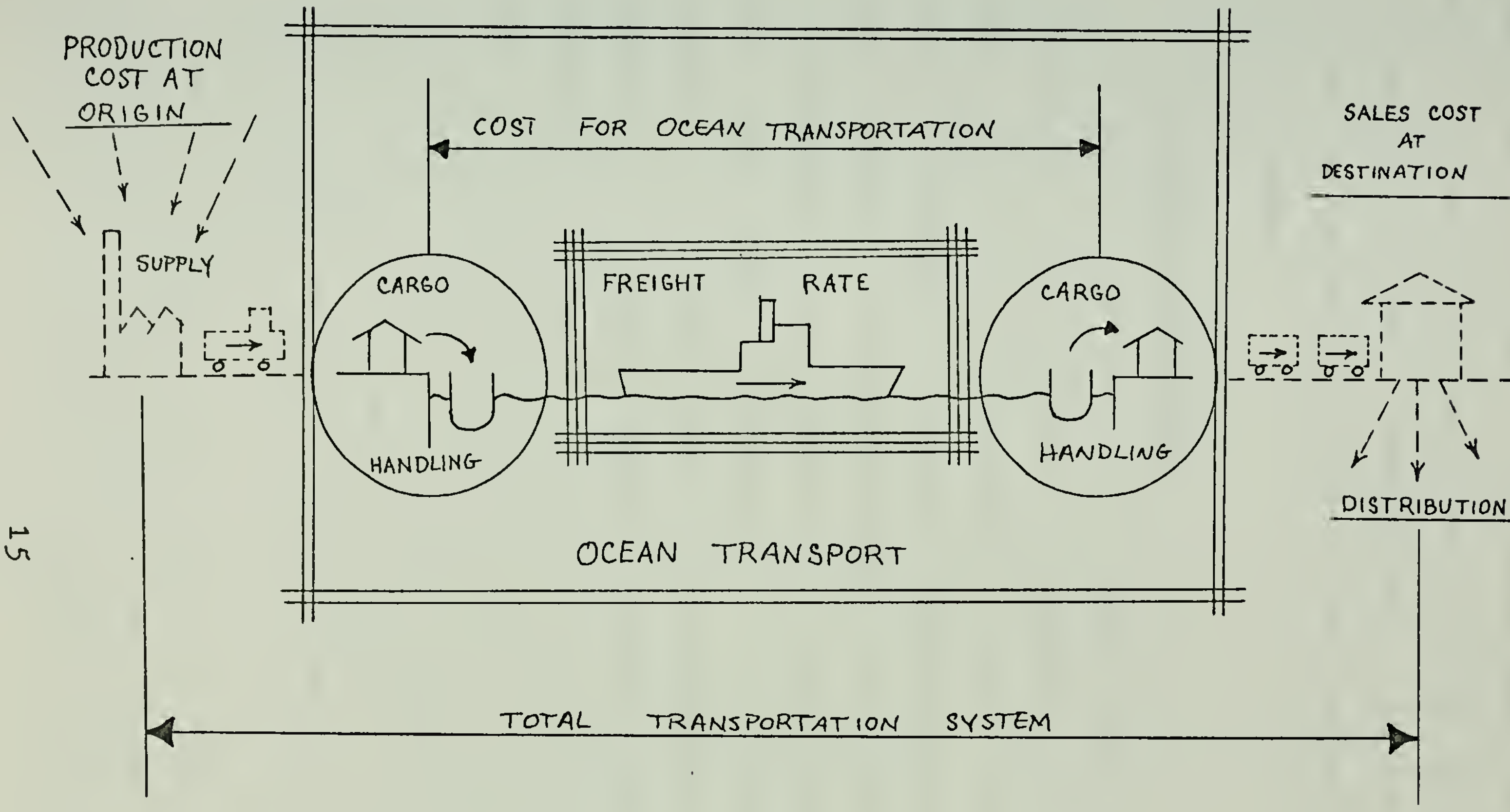


Figure 1 OCEAN TRANSPORTATION SYSTEM REF [17]

facilities, the cargo is handled so that another mode of travel can be utilized. This constitutes the second element. In the last element, we will lump all of the remaining parts of a general transportation system. These will include the various distribution and intermediate transportation systems.[1]

1.2 Subsystem Interactions

We want to look now at the interactions between the three parts. As described, the elements of the transportation system function in series, thus the capacity and the related efficiency of the total system can be affected by a single element. Any system design will attempt to size each of the elements so that there will be no disparity in capacity between single units because of the resulting inefficiencies. An exception would be the planning of excess capacity to be utilized during a future period of growth. Conceptually this model should prove useful and as more ports and shipping routes are opened, the same principle can be used to describe the larger total system. This simple model ignores the management problem of capacity utilization in large networks, but the interactions should be more easily understood.

The major purpose of the ship is to act as a mode of containment and transportation between ports. The terminal also serves as a location to inventory cargo so that loading

and unloading of the ship can be achieved without delay. Many methods have been proposed for reducing the cargo handling at the terminals and thus increasing their capacity and efficiency. One such attempt is the containerization of cargo. Instead of handling the different cargoes individually, containers are used, thus simplifying the loading problems and reducing breakage and loss of cargo. Over the last few years this method has become even more popular, especially with customers that transport small, high value items, such as electronic equipment. For large bulk cargoes ship barge systems have been developed.

The interaction between the ship and terminal has many different facets. They can be related to a time delay in port. When a ship arrives, it awaits space next to the terminal. Once along side, the crane will continuously handle containers during the loading operation. The duration of this evolution depends directly upon the reach, carrying capacity and speed of the crane. After the incoming cargo is off loaded and the outgoing cargo is on loaded, the ship may have to wait for favorable navigation conditions such as slack water at high tide so that the ship can maneuver out of port safely. The interaction is completed in the same way that it started, with the ship at sea proceeding between ports at its operating speed.

The interactions between the port terminal and the rest

of the transportation system can be defined along similar lines. It becomes evident that there is a large management function at the terminals. The skill developed in these functions and the capacities of each of the elements determines the volume of cargo flow in the total system. To say that the transportation system is capacity limited by a single element should require that the element is operating with maximum efficiency. Otherwise, capacity can be increased without additional capital investment. The complex problem of capcity determination will play an important role in the total transportation system design. It should be obvious that when the total system is operating at capacity, subsystems with excess capacity are not desirable unless there are future plans for expansion. This points out the requirement that the design cover the whole of the transportation system. Many papers have addressed themselves to the overall capcity balancing problem. The reader is referred to Erichsen[2] and Hancock[3].

Independent of the overall transportation system design, there will be a stage in the total design when the capabilities and costs are desired of a ship that can interact with a given terminal configuration. This may be for an addition of shipping capacity on an already existing route or for an entirely new transportation system. We are interested in this interaction between the customer and the designer.

CHAPTER II.

SHIP DESIGN PROCESS

2.1 General

The ship design process is that set of actions involved from the initial desire to build a ship until the final delivery of the product. In some circumstances, one or both of these events may be difficult to determine. The process involves two groups. One is the owner or user group and the other is the designer or builder group. The traditional process (see Figure 2) involves the determination of the owner's expectations and his statement as to the capabilities desired in the ship design. Many times this would be the first formal step in the process. The need for the ship may result from intuitive feelings based upon years of experience as a ship operator. Whatever the source, a gap is identified between supply and demand for services. The owner's requirements have traditionally been quite explicit -- the speed, endurance, and payload of the design being specified. This statement provides the means by which the design passed to the engineer from the owner. As depicted in the block diagram, the designer then proceeds to implement a design procedure that results in a feasible design which meets the owner's requirements. At that point, the owner would decide

SHIP DESIGN PROCESS

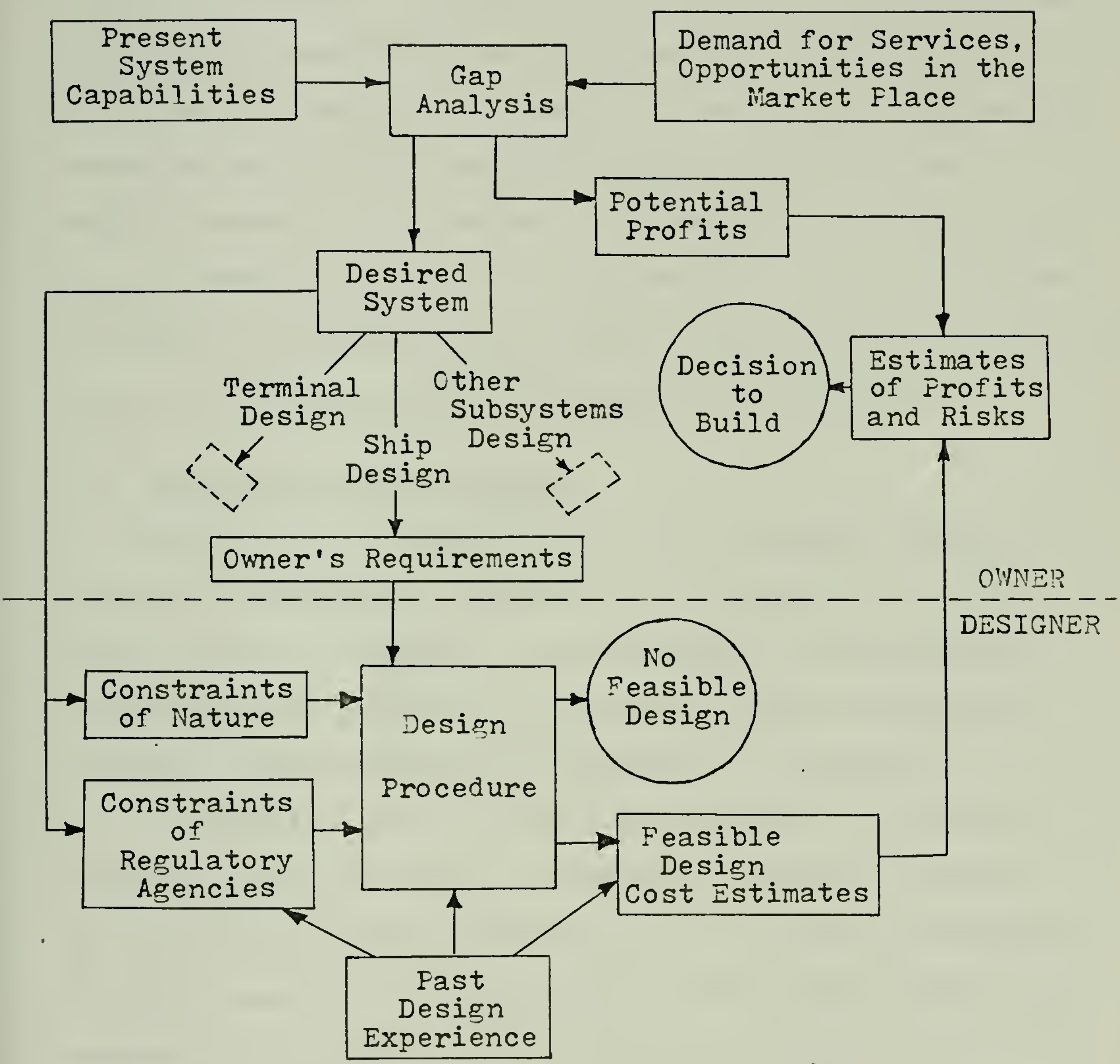


Figure 2

if the ship design should continue to a building phase.

The steps listed in Figure 2 are representative of the process. They may either be found explicitly or implicitly in the design effort. There are two factors which distinguish the process. In general, it is a single pass system. Inside each phase there may be iteration, but there is no provision of changing the inputs to any phase. The second characteristic is the parallel design feature of the other elements of the system. The decision to build does not necessarily provide for a system wide evaluation after the owner's requirements are fixed. Before criticizing this form, let us investigate the nature of the system.

2.2 Normative Design Process

From the ship design process, the decisions that must be made are identified. They are in turn associated with a level of decision making. The following conceptual model exemplifies the hierarchy of decision making that makes up the ship design process (See Figure 3). According to M. D. Mesarovic, et. al., there is no single best model for describing the multilevel, hierarchial system. However, the essential characteristics are a "...vertical arrangement of subsystems, and [a] dependence of the higher level subsystems upon the actual performance of the lower levels."[4]

In the Figure, there is no significance to the number of levels drawn. They are used only to show possible

INFORMATION FLOWS
IN A NORMATIVE DESIGN PROCESS

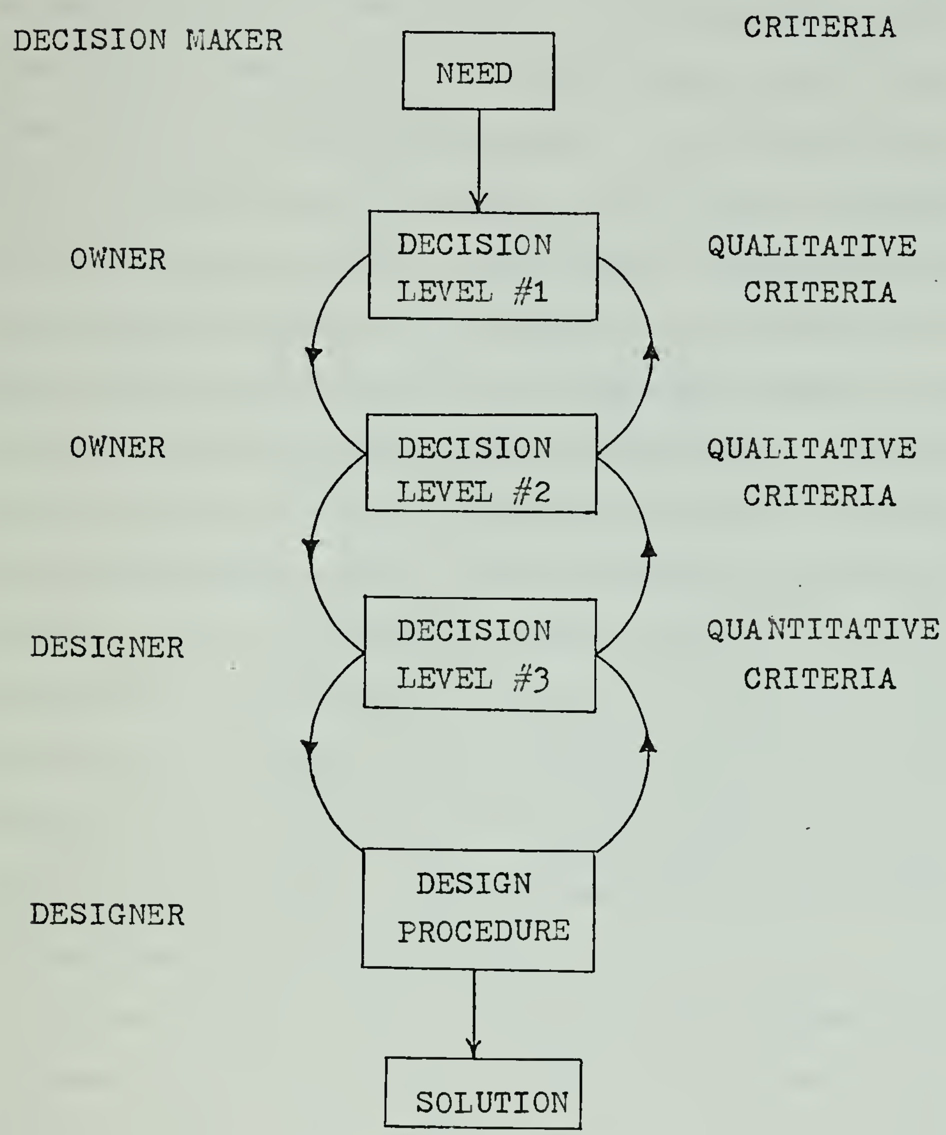


Figure 3

relationships. The input to the process is the result of an analysis which identifies a need. The output of the process is a solution (design) which hopefully meets this need to the satisfaction of the owner. At the higher levels, the owner plays a major role. At the lower levels, the designer accomplishes the design procedure. From each level, requirements and guidelines are passed down to the next lower level, and from each lower level the current results and unresolved decisions are passed up for action. The levels of decision making have been identified as different stages at which tradeoffs between criteria are accomplished. Associated with each level is a set of criteria which are related to the decisions being made. The decisions concerning certain criteria can be delegated to lower stages in the design. In this model of the design process, the owner has responsibility over all decision levels. Those involving quantitative critieria such as cost have been identified with the lower stages in the process. This assumes that the owner's preferences have been identified.

In the current design practice, the designer receives the owner's requirements and stops as soon as a good solution is reached. This means that the last two stages of the design process are in equilibrium with each other, but not with the rest of the system. That is, the output of the designer is a feasible solution which satisfies the original

owner's requirements. The traditional process terminates here. If, instead of the last stages being conducted independent of the rest of the system, continuous feedback and adjustment were possible, a more desired result may be obtained. This would require more coordination of effort between the owner and the designer throughout the design.

By setting up a formal system to handle the various levels of decision making, the owner will help control the whole design process by giving better direction to lower level management. This would be most important in the design of new ship types where the final desired solution is not obvious to the owner.

This suggests that one of the first steps in the design process is the determination of a set of criteria and ordering them in a way which reflects their importance to the owner. In the normative process, some of these criteria are assigned to lower levels of decision making. Usually the criteria can be categorized as either quantifiable or non-quantifiable. The quantifiable criteria can be easily delegated to lower levels of decision making due to the straightforward procedures involved in the tradeoffs. This does not prevent some or all of the nonquantifiable criteria from also being assigned. The owner can never comfortably remove himself from the tradeoffs required by the nonquantifiable criteria. He may, however, quantify his preferences

so that lower levels can perform tradeoffs similar to those accomplished for quantifiable criteria in the decision process. An example of such a delegation is in the economic criteria which identifies the owner's preferences for changes in the timing of cash flows. By identifying a discount factor consistant with the owner's time value of money, the designer can proceed with the economic evaluation as if the criteria were entirely quantifiable. This relieves the owner of the need to make tradeoffs of a large number of cases but still allows him to influence the process. An example of this influence would be a change in the discount rate after several iterations. This method of manipulating the economic criteria would reflect uncertainty of the owner in his actual preferences.

For an individual as the owner, the decision process presents few conflicts of interest. As the number and diversity of those in the decision group grows, internal conflicts arise when preferences are expressed. This becomes a significant problem when the owner is as large as the government. The socio-political environment may then prevent an explicit definition of the preferences due to the nature of the system being designed. The problems of decision making involved in this environment are felt most strongly by those who act as representatives for the government. The decisions based on preferences will produce focal

points for conflicting interest groups. This tends to reduce the area in which explicit decisions are made to those in which mutual agreement on the method of quantifying the criteria can be achieved. This often results in the qualitative criteria being either ignored or being considered informally.

This multilevel, hierarchial system is compatible with the ship design process. It has the advantages of isolating the decision maker and setting responsibilities. This then leads to reliable subsystems. In particular, the multilevel system offers an improvement over other systems in the utilization of resources when solving large scale complex problems. It also provides more flexibility and in general can be expected to produce better system output. This does not suggest that the system is ideal. Some of the disadvantages are its complex operation or behavior. As such, it is difficult to analyze or comprehend. It also is difficult for one to control or influence its progress. However, the multilevel, hierarchial system has proven that it's general qualities are better than other systems designed to handle large programs.

2.3 Proposed Design Process

Any proposed system must provide a method for the flow of information from higher authority, performance of its design task, and the reporting of results using the developed

criteria to the next higher level of decision making. The upward flow of information will be used to determine if there is need for further iteration to achieve a better overall design. This is done by investigating tradeoffs between various criteria and their associated costs. The information that would be necessary to accomplish this task would include first, the values of the decision variable and an estimate of the confidence limits for these values. Secondly, the information should include a sensitivity analysis that would show the decision maker the resulting effect on the criteria measures for changes in the values of selected variables. The proposed design process (Figure 4) attempts to incorporate these requirements.

The best way to understand the major features of the proposed change is to contrast this design process with the traditional process covered earlier. First, the proposed design process, being iterative, takes more time and effort. Where the designers objectives are fairly clear in the traditional process, the guidelines now provide for much more leeway in the actual design. This in turn requires additional effort. The process requires increased interaction between the owner and designers so that the designer can determine the preferences of the owner. The owner's identification of the criteria and measures of effectiveness should be given substantial attention so that this

MODEL OF THE PROPOSED
SHIP DESIGN PROCESS

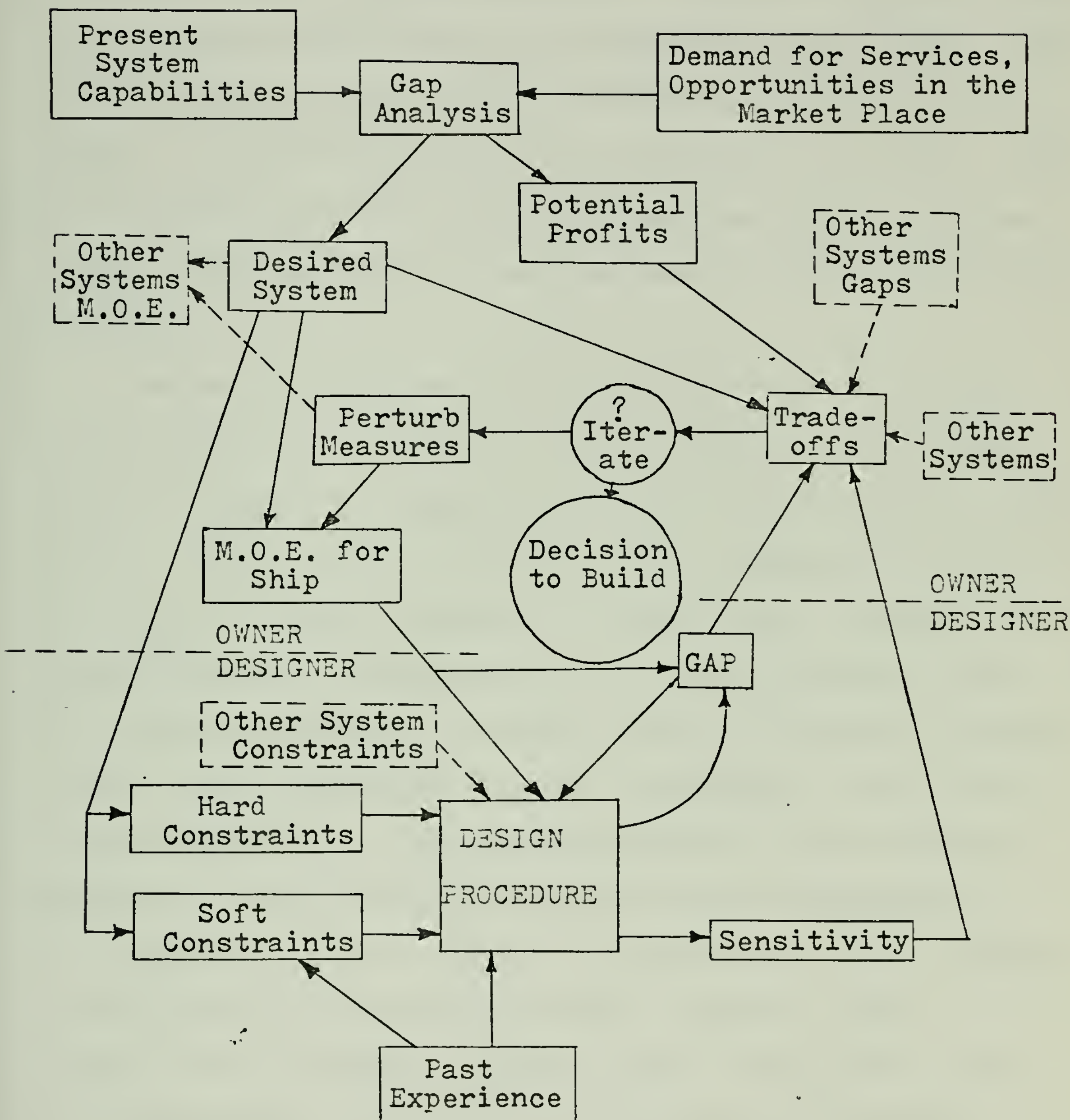


Figure 4

interaction is effective.

In both systems the owner has the responsibility of making his desires known and making the final decision to build the ship. In the traditional process, the owner would use a previous ship design to communicate his desires. When this luxury no longer exists, it becomes necessary to formalize the method by which such preferences were made. This is especially true for large systems when there is no one single decision maker who can perform the vital integration function.

One way to rationalize the prevalence of the traditional system is to study the time history of ship design. Over the years the design process identified successful ship types. This meant that the individual design efforts did not require formal iteration to achieve good designs. By perpetuation and extrapolation of the ship features that had proven themselves in actual service, sufficient success in the ship deisng effort could be achieved. This identifies a situation in which the traditional approach may be preferred. When the changes in the need as percieved by the owner are fairly constant over time, newer ship designs can be based on the more successful existing ships. A change in the traditional method would thus require that new requirements be placed on the ocean transportation system. These would be similar to the needs generated which

caused the building of liquid natural gas (LNG) ships where no similar ship type previously existed.

In order that the additional benefits identified by the normative model may be incorporated in the ship design process, a new method was proposed. The major differences were first, the iterative nature of the process; secondly, the change in the form of the owner's requirements entering the design procedure. This means that the designer will no longer identify merely a feasible solution. In turn, this requires a change in the perspective of the designer and the owner. No change was made in the actual design procedures. The next chapter identifes a sample program which will be used to demonstrate the proposed design process.

CHAPTER III.

PROBLEM STATEMENT

3.1 Scenario

A large U. S. owner, an operator of containerships, desires to expand operations between San Diego, California, and Yokohama, Japan. The company is interested in purchasing a single ship to increase the shipping capacity of this route. The company presently has no available ships to transport the increased demand for cotton and leather goods in Japan. If present rates prevail, it is assumed that each ton of cargo transported will generate $100 in revenues for the company. At the present time, there are no arrangements anticipated for the backhaul of cargo. The company usually does not consider the backhaul when making their capital investment decisions because the quantity of cargo handled on the return voyage is so small that almost any reasonably sized ship would be capable of providing the capacity. Each alternative would then generate the same backhaul revenues, and thus would not affect the decision to be made.

The trade route imposes some restrictions on the alternatives. First, the terminal facilities are such that a single loading sequence will not be able to provide more than 1200 containers without excessive delays. Secondly,

the pierside cranes maximum reach restricts the ships beam to 110 feet. Finally, the harbor channel restricts the ship's draft to be less than 37'. The ports have an average charge associated with the pilotage and tug fees which is incurred upon entering or departing a port. Past experience estimates these to average $1,000 per port call. While in port, there are additional wharfage and port fees which are determined by the number of days in port. The port delay times have historically averaged two days per port call. While in port, there are additional wharfage and port fees which are determined by the number of days in port. The port delay times have historically averaged two days per port call.

The container size in use is a 20' X 8' X 8' container which meets the American Standards Association requirements. Each full container has been estimated to weigh 16.7 tons. This restricts the stacking of containers, one on top of another without an intervening, supporting deck.

In order that all costs and prices be consistant, the base year of 1969 was selected. The prevailing economic conditions in the U.S. in 1969 were such that the operator could be assured of obtaining a 55 per cent building subsidy from the Maritime Administration upon request.[5] In addition, the company was anticipating financing three quarters of the unsubsidized costs by incurring a 25 year loan

at ten per cent which would be insured by the government. Other alternative routes have been generating a yield on the companies original investment after tax of about twenty per cent. The company feels that any new route should generate a similar yield. In addition to the subsidy, the company will be able to take a seven per cent investment tax credit. For comparisons between alternatives, this will be translated into a reduction of initial out-of-pocket costs.

3.2 Design Problem

The above scenario presents several questions to be answered. Here we will attempt to identify the characteristics of the design which would be obtained during a preliminary design stage. This effort will require that design constraints be translated so that non-feasible alternatives can be eliminated from consideration. After a choice is made of the ship's characteristics, its confidence must be evaluated taking into account possible variations due to uncertainty in the information available in the design. This will help to measure the uniqueness of the design.

Now the problem of selecting a good design must be addressed. In the next chapter, measures will be developed that will help to insure consistancy in our selection as well as providing a reference from which to base our decisions.

CHAPTER IV.

SHIP DESIGN CRITERIA

The existance of different commercial ship designs to accomplish similar tasks can be explained by the environment and experience level of those involved in the design. The design selection process is greatly affected by these factors because the real-world environment will influence individually each decision maker. Insight as to what determines the merit of a ship design thus requires investigation of the decision maker's preferences.

The objectives of the ship system which are to be satisfied by the decision maker's choice of alternatives are complex, however, a simple statement would list the commercial ship as primarily a means of improving the economic welfare of its owners by providing a marketable service.

4.1 Criteria

The difference between the worth of ships is based on a number of criteria from which the merit of a ship is determined. Conceptually there is a single list of criteria whose various orderings reflect the preferences of the decision maker. The following figure attempts to give a sample catalog of criteria. The determination of the relative importance of these criteria is a function of the decision maker.

Table 1

CATALOGUE OF CRITERIA

Ref. [3,6,7,9,27,36,37,39]

I. ECONOMIC

Profits
Durability
Asset Life
Obsolescence
Salvage Value

II. MISSION RELATED CAPABILITIES

Transport Mission

Speed
Endurance, Range
Capacity, Payload, Cargo Type

Patrol Mission

Search
Investigate
Plant and Retrieve
Secure

Interaction Mission

Engagement
Station-keeping
Avoidance, Defense

III. OVERALL SYSTEM CAPABILITIES

Mobility
Viability
Flexibility
Survivability
Operatability
Effectiveness

IV. MARKETABLE QUALITIES

Aesthetic Value, Style, Color
Quality
Prestige
Personal Satisfaction

V. RISKS AND UNCERTAINTIES

Investment Risks
Future Uncertainties
Reliabilility
Maintainability
Availability

The commercial ship owner, on one hand, is ultimately interested in economic criteria and in particular profits, whereas a warship's merit will be a strong function of the ship's mission capabilities. Where the ability of providing defense from attack may be important in the warship, this criteria is ignored in commercial ship design. Also, the economic criteria loses its eminence for a warship design because profits are no longer meaningful.

Another difference between designs is reflected in the variation of risks involved in the design and the risk preferences of the decision maker. The term 'risk' refers to the possible outcomes associated with uncertain future events. For a commercial ship this may be in the form of unexpected breakdowns resulting in expenditure of funds and delays in operation. A risk associated with warship design may be represented by possible threats such as a surprise enemy attack. The risk preferences relate to the utility function of the decision maker. From this it is possible to determine the mechanism by which the decision maker assigns weights to criteria, taking into account the values and risks involved for each alternative. The process of determining a decision maker's utility function uses successive lottery choices where the decision maker is asked to determine his preference between only two events. It is important to note that the decision maker is not always consistant in these choices.

The risks of the design are measured by many of the listed criteria.

The multiattributed analysis of Keeney [6] and many others could be applicable in helping to quantify the owners preferences. For an example, if an owner of a commercial ship experiences a situation where a breakdown only occurred once during the life of the ship which required assistance to get into port, the risks may be acceptable. On the other hand, a single weapon impact on a warship may result in a total loss of the vessel and perhaps result in the loss of other units which it may have been defending. The risks are high and even though the event may be very unlikely, the resulting risk preferences of the decision maker may cause changes in the ordering of the design criteria.

4.2 Measures of Effectiveness

To be useful in a modeling context, each of the above criteria must have an associated measure. For those criteria which are basically quantitative this presents no problem. The economic criteria can be easily measured by dollars. The others, however, present a real problem, both to the designer and to the owner. This becomes most evident when it is necessary to make a decision based on tradeoffs between two qualitative criteria. It is not uncommon to assign measures to these qualifiers. The regulatory bodies have taken the liberty to associate floodable length with the safety of the

ship at sea.[7] This is satisfactory if the proper response is obtained by use of such indirect measures.

It is not the purpose of this paper to propose measures for the criteria. This is a function of the individual decision maker. For the remainder of the paper, we will handle only the more accepted measures. We will use dollars as a measure of the economic criteria and as the measure of effectiveness for judging the ship design. Other quantitative criteria will be introduced as constraints, giving minimum standards for the design to satisfy, the freeboard requirement is such a constraint.

4.3 Measure of Economic Criteria

When making a capital investment decision it is important to identify all of the interactions that can affect the economic returns to the decision maker over the life of the decision. These interactions may be related indirectly as would be the case when the reputation of a ship affects the willingness of customers to do business. For this paper, we are restricting our interests to the direct economic effects.

4.3.1. General

In the context of the normative process, the decision maker attempts to tradeoff different criteria in terms of the possible changes in profit and other qualitative aspects.

Once the tradeoffs are made and the owner's requirements are identified, one economic measure of the goodness of a design is its ability to provide profit to the owner. In ship design, this measure is subject to uncertainty because of the lack of information about revenues over the life of the ship. The measures in the literature assume that the revenues are unknown because a good forecast cannot be obtained, the result being that measures typically involve costs only. For the ship design, the costs can be predicted with a fair degree of certainty.

If one assumes that the ship will be built and we are merely interested in determining the best designs out of the various alternatives, then the simplified problem can be analyzed by including revenues. A marketing study could provide an estimate of the income expected from the cargo transported. This would help indicate the relative earning ability of each design. The freight rate that would be obtained will be used to drive the solution technique in the sample problem.

The owner's requirement for a desired cargo flow rate would be calculated as shown in the following figure which depicts estimates of revenues and costs for shipping a different cargo transfer rates. The owner would select a value of the payload transported per year that would maximize his profits. Along with this point estimate, he would also have an estimate of costs involved if the design

STAPLE CAPITAL DECISION MODEL

(SINGLE SHIP)

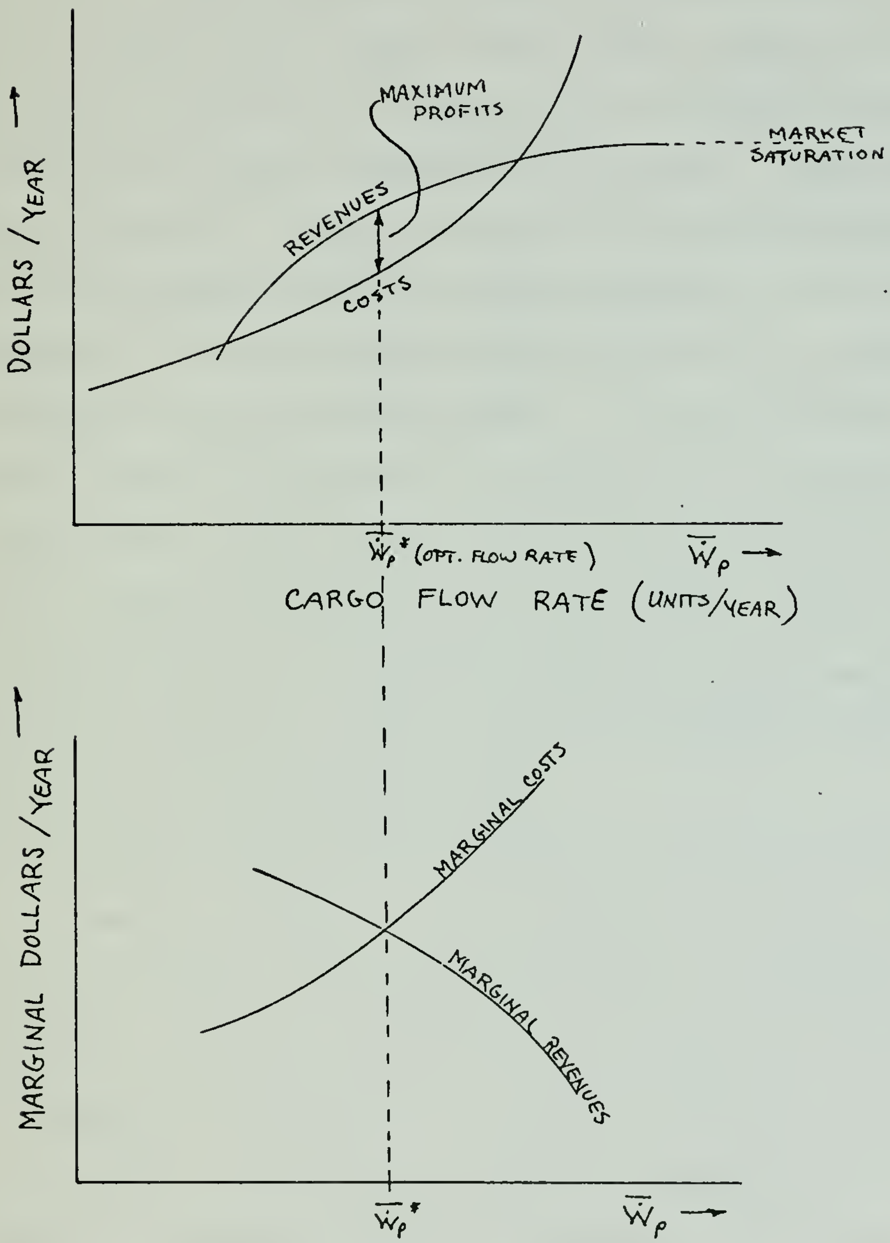


Figure 5

fluctuates from this estimate. This cost can be associated with a penalty cost to the designer for deviating from the owner's original requirement. Given the flow rate of cargo required, the owner is interested in the design that minimizes the cost of this service, subject to restrictions placed on the design. The owner would easily change his requirement on the flow rate of cargo if in so doing he would permit a design that could increase his profits. This gives the owner two options. First, he could direct the designer to design for a certain speed and cargo capacity, as is the present practice, or the designer could perform the evaluation to determine the new requirements. In this case the designer would need the criteria for setting up a decision model. This should require less work of the owner than to determine the owner's requirements, and it would reduce the number of iterations of the proposed design process because the owner would not have to wait until the designer proposed each modification to the requirements.

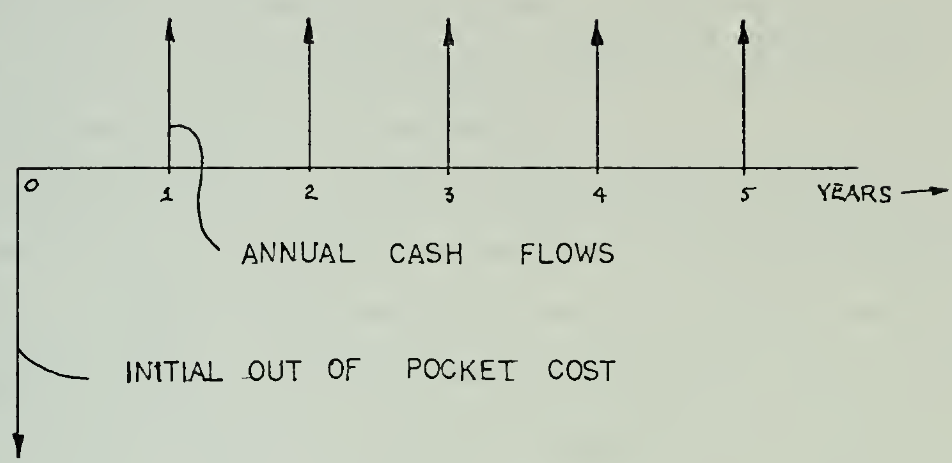
For the sample problem, the decision model is formulated in terms of economic criteria. By defining the general form of the revenue schedule, the cash flows can be determined by the designer. The model assumes a fixed freight rate for material transported between two specified locations. The designer would then be able to perform the tradeoffs in the design procedure concerned with the economic criteria once

the owner's preferences are identified. One way for the owner to project his desires is to identify the parameters for the calculation of the net present value of a design alternative.

4.3.2. Net Present Value

The Net Present Value (NPV) calculation takes a series of cash flows and determines an equivalent lump sum value at a specified point in time. It is based on the premise that there is a time value of money. The assumption is that a person will be indifferent to receiving one dollar today or one plus X dollars at some later time. This value is inferred from the fact that the one dollar can be invested today and have earned X additional dollars by the end of the period. We define the value of X as the discount factor. In general, the cash flows can be continuous or discrete, but for a continuous cash flow there will be an instantaneous discount rate. The cash flows may either be positive or negative. Also the discount factor may be a function of time.

For ease of computation and also because of limitations on the projection of future cash flows, we will restrict the discussion to discrete cash flows and a constant discount rate. See Figure 6. Since data is available on an annual basis, we will use annual costs directly. The horizon of our calculations will be the expected lifetime of a ship.



$$NPV \quad I + C \left[\frac{(1+i)^{25} - 1}{i(1+i)^{25}} \right] - \frac{SV}{(1+i)^{25}}$$

$I \equiv$ Initial Investment

$C \equiv$ Annual Cash Flows (Assumed constant)

$i \equiv$ Annual Discount Factor

$SV \equiv$ Salvage Value

Figure 6

It has been standard practice to use a twenty-five year life for ships. This has been substantiated by studies conducted by John McMullen Associated, Inc. for the U. S. Navy in 1967. At the end of the twenty-five years, the vessel will have a scrap value. This is usually a fraction of the initial cost and will be an input to the model.

Looking at the operating costs when performing our present value calculation, we can make some important generalities. First, the operating level of the ship can be assumed constant for the duration of its life. This indicates that the crew hours and the fuel usage per year will be constant. We can then calculate annual operating costs if the wages and the price of fuel are known. If a current market price is assumed, then the discount factor could adjust for the effects of inflation. This may not be adequate if there is a restriction in the supply of fuel oil that causes it to increase in price faster than other expenses. One solution would be to utilize two discount rates, one for each different cash flow but for this problem we will assume only a single discount factor.

Until now we have not included the maintenance and overhaul costs. These are significant when taken over the life of the ship. They should be estimated and included in the NPV calculation. These costs are dependent on the policies of the owner and data is not readily available. They will

be treated in this model as an annual cost whose value will be a fraction of the initial ship cost.

The following list gives the major restrictions and limitations of our use of NPV.

(1) Cash flows must be on an after tax basis.

(2) Does not account for uncertainty in cash flows.

(3) Assumes that there is no capital rationing.

(4) Gives a poor measure for liquidity or timing preferences.[8]

Depending on the form of the capital rationing, modifications to the straight NPV calculation can be made so that comparisons between designs are more valid. One method involves varying the discount factor and noting whether or not the relative merit of competing designs change. Another would impose a variable discount factor. This could model a temporary cut-off rate. For a strict capital rationing which limits the initial cost of the investment, the addition of cost constraints to the design model would be another method of accounting for the rationing of capital.

The other limitations of the net present value method indicates that it will not always serve as a good single measure of economic worth of the different design alternatives. In order to compare the results from this measure of effectiveness or objective with some others which are commonly used, the model calculates independently the values

of the capital recovery factor and the required freight rate for each alternative. This leaves open the option of selecting the objective to be used.

4.3.3 Capital Recovery Factor

The Capital Recovery Factor (See Figure 7 for Definition) is the resultant of dividing the value of the annual cash flow by the initial investment. This can be used to find an implied or yield rate. If the cash flows and the investment base is the same as for the N.P.V. calculation, and the annual cash flows assumed are assumed constant, the results will be compatable with the N.P.V. measure. The capital recovery factor calculated is based on the total investment and as such is not consistant with the net present value measure.

4.3.4 Required Freight Rate

The Required Freight Rate (See Figure 7 for Definition) is that cost that must be charged to break even with the costs of operation, including depreciation or some return on the original investment. This calculation does not require knowledge about revenues and is insensitive to change in tax rates.

$$CRF = \frac{1. - (2. + 3. + 5.)}{6.}$$

$$RFR\ (\$/TON) = \frac{2. + 3. + 4.}{7.}$$

Where:

1. - Annual gross revenue
2. - Annual operating cost
3. - Annual loan payments
4. - Annual depreciation allowance
5. - Annual tax payment
6. - Out of pocket investment
7. - Payload weight in tons

Figure 7

CHAPTER V.

ALTERNATIVES

5.1 Decision Variables

The decision variables were selected to simplify the determination of the objective surface used by the optimization technique. The model must incorporate variables that would first identify the physical form of the ship; second, identify the loaded condition, and finally identify the operational capabilities. By using the linear dimensions and the coefficients of form, the geometry was determined. The specification of the draft and the displacement determined full load condition. The only ship performance investigated was the speed of a transit. Thus the ship's speed was used. The following is a list of the decision variables.

X_1........	Displacement (Δ)
X_2........	Length (L)
X_3........	Beam (B)
X_4........	Draft (T)
X_5........	Depth (D)
X_6........	Prismatic Coefficient (CP)
X_7........	Speed (V)

Table 2

Note that the midship coefficient is a dependent variable. CM = CB/ CP.

5.2 Design Alternatives

The various alternatives that will be investigated can be identified as a set of the design variables. For each alternative, other parameters are held constant except when sensitivity to changes of these parameters were tested. This method of alternative identification was selected to maintain simplicity in the design model and to facilitate its understanding. Also areas of scarce information played a role in the final set of variables.

The ship capabilities which have a major effect on the ship owner are the load capacity, speed, and endurance of the vessel. Prior to evaluating any design these must be known. Each contains a continuous range of possible values. For this problem, the endurance will be treated as a fixed quantity. The speed and load capacity of a given size and shape ship are now related. After the propulsion plant configuration is determined, it is possible to evaluate the available space and weight for cargo. The size of the propulsion plant is a strong function of speed for any given ship geometry. It should be obvious that the alternatives can be identified by the decision variables listed earlier.

In the search for the better alternative designs, the feasible space must be identified. The following areas are discussed to identify the limitations of possible alternatives studied by the design model.

5.2.1. Engine Arrangements

The various basic space arrangements of either the engine room aft or amidships cannot be handled in this problem. The factors introduced by letting the location of the engine space vary are difficult to model. Probably the most important reason is that the internal arrangement is not unique for any given ship geometry and capability. The variations in payloads due to the differences in the location of engine spaces are also difficult to estimate during the preliminary design. Unless one is willing to enlarge the scope of the problem by introducing the problem of trim in the full load condition and all of the other ramifications, the benefits of a more detailed study in this area may not prove useful. It would require an extra step of optimization which would identify the best location of the engine space for a given alternative design. The cost of this separate procedure may well be of the same order of magnitude as the cost of the rest of the program. This increase in costs was treated as unreasonable. As previously stated, it is not the intent to determine an actual design that will be built, but rather to investigate the design alternatives in a preliminary phase. Thus the alternatives are restricted by having their engine space located aft.

In addition to the engine space location, the propulsion plant configuration is dependent on the number of

propellers and shafts in the design. In the model either a single or double screw arrangement may be selected. These restrictions are imposed by the program user. The model only adjusts the number of engines and the associated operating levels and does not handle the actual engine arrangement. The differences in the weights of units other than the engines are not considered significant for the different configurations. There is, however, an adjustment made for the differences in appendage drag.

5.2.2. Ballast

As used in this paper, ballast is not considered part of the payload. An upper limit on payload for each alternative would occur when no ballast is being transported by a proposed design. There may be a configuration where ballast is transported. Of course, this is not an intuitively appealing situation, but there may be a configuration where ballast may be advantageous. This may occur if the ship is stability limited. If by carrying extra ballast an additional container is transported, the benefits could outweigh the costs. Even though ballast may be "off limits" to most designers and operators, the only direct cost associated with the ballast in a design with a fixed displacement is in the initial installation. The inclusion of ballast impacts on the payload carried at the specified speed and endurance. For the purpose of this study, the cost of installed ballast will be taken as $1,000 per ton. This

is higher than the real costs experienced, thus should help to minimize ballast wherever possible.

5.2.3 Full Load Condition

It is realized that designing to the fuel load condition does not reflect all of the possible operating conditions which exist. The program does not address directly the backhaul or other ballasted conditions. Through interaction with the program, however, it may be possible to develop a design model that could incorporate such a ballast transit. This would require that the designer interact with the program and the results be carefully interpreted. The design model could in this way serve as a small part of an overall system design optimization.

5.2.4 Volume

Using a similar argument as that for disregarding engine space location, the volume constraints of the problem were ignored. Except for the obvious case of determining the container configuration, the volumes were not tested. A final hand calculation of volumes was accomplished for the final results. From these hands calculations, it was found that the designer may wish to be more careful in the handling of the volume constraints. First, it was thought the ship may be only weight limited for all but the container configuration. That would mean that the space not used by

the container configuration would be ample for the volume of any other weight group such as fuel.

5.2.5. <u>Containers</u>

The variation in container sizes has been standardized since 1961. The American Standards Association standard container dimensions are given in Table 2 . In this study, only the 20' X 8' X 8' non-refrigerator containers were used. It was assumed that they would possess the strength necessary to stack the containers six high. This standard of the ASA is not accepted internationally, the International Organization for Standards (I.S.O.) calls for the stacking of only four high.[9]

5.2.6. <u>Terminal Interaction</u>

The various interactions with the terminal were treated as parameters in the design. It was assumed that the ship relied on pierside handling and the average port delay time was not sensitive in the range of the loading capacity of the ship. This could have been modeled but again this level of detail was beyond the scope of the problem. There was one factor of the interaction that was incorporated. The model is constrained to a maximum number of containers per trip. This relates to the capacity of the terminal facilities.

Table 3
Ref [8]

A.S.A. Standard Container Dimensions And Weights

Length	Width	Height	Maximum Gross Weight
40' - 0" $^{+0''}_{-\frac{3}{8}''}$	8' - 0" $^{+0''}_{-\frac{3}{16}''}$	8' - 0" $^{+0''}_{-\frac{3}{16}''}$	30 long tons
29' - 11.25" $^{+0''}_{-\frac{3}{8}''}$	8' - 0" $^{+0''}_{-\frac{3}{16}''}$	8' - 0" $^{+0''}_{-\frac{3}{16}''}$	25 long tons
19' - 10.25" $^{+0''}_{-\frac{1}{4}''}$	8' - 0" $^{+0''}_{-\frac{3}{16}''}$	8' - 0" $^{+0''}_{-\frac{3}{16}''}$	20 long tons
9' - 9.75" $^{+0}_{-\frac{3}{16}''}$	8' - 0" $^{+0}_{-\frac{3}{16}''}$	8' - 0" $^{+0}_{-\frac{3}{16}''}$	10 long tons

5.2.7. Propeller Alternatives

It was decided to handle single or double shafts separately. However, the effects on the overall propulsive efficiency due to different propeller designs were ignored. The problems associated with the propeller design could have been incorporated at the expense of simplicity. Instead, it was decided to test the sensitivity of the overall results to changes in an arbitrary propulsive coefficient. This would then indicate if more detail would be necessary.

CHAPTER VI.

DECISION MODEL

The objective of the optimization model will be to maximize the net present value of cash flows to the ship owners due to the initial cost and annual cash flows.

Each alternative generated will be subject to restrictions from rules imposed by the regulatory agencies, the restrictions due to navigational considerations, and restrictions due to either data limitations or owners requirements. The following is a simplified mathematical model of the problem. The expressions are given in a simplified form. The decision variables were covered in Chapter V.

6.1 Objective Function

As determined earlier, the net present value measure for the capital decision problem could be one of the criteria used in making choices among alternative designs. Our decision model determined the net present value of the cash flows to the owner by calculating the initial building and subsequent annual costs. The objective of the program will be to maximize the net present value of the design. The objective function is not expressed solely as closed form equations, because some of the data is extracted from known

tables.

6.2 Constraints

During the design process, there are several constraints that must be observed. These can be defined as either soft or hard constraints of the problem. They help determine the feasible set of design alternatives. The hard constraints refer to the constraints imposed by technology and the laws of nature. These would include the maximum draft limitation due to the channel depth and the limitations on geometry of the ship due to strength limitations. The exact value of the hard constraints are sometimes difficult to determine. For example, the limit of strength is not well defined. In these cases, rules of thumb have been developed. These are the result of attempts by the regulatory agencies to quantify the factors involved.

The soft constraints, on the other hand, have no physical significance. They result, not from ship design alternative, but from requirements of the owner or designer. These could be imposed in order to insure compatibility with other elements in the total design of the ocean transportation system. The maximum constraint on containers permitted per trip is an example of such a soft constraint. It could also be a limit indicating the range of data or experience. The limit is obvious in the powering calculation. The soft constraints thus limits the set of feasible design

alternatives. Even though there may be good alternatives outside the experience of a designer he may not have confidence in its potential. For this problem, we have imposed soft constraints due to the availability of data. If these become tight constraints during the final iterations of the design then a direction will at least be identified for further investigations.

For this problem, we have segregated the constraints into four areas: Those due to the requirements of regulatory bodies, navigational restrictions, interaction restrictions, and data restrictions. (See Figure 8)

MATHEMATICAL STATEMENT OF THE
CONTAINERSHIP DESIGN PROBLEM

MAXIMIZE ⓪ NPV OF CASH FLOWS
(STRONGLY NON-LINEAR, CONTAINS INTEGER VARIABLES X_{CO} AND X_{PP})

SUBJECT TO:

ARCHIMEDES PRINCIPLE		①	$\sum \text{WEIGHTS} = \Delta$ (STRONGLY NON-LINEAR, CONTAINS INTEGER VARIABLE X_{PP})
REGULATORY AGENCIES	STABILITY	②	$GM_{ACTUAL} \geq GM_{REQUIRED}$ (STRONGLY NON-LINEAR) 1
	FREEBOARD	③	$FB_{ACTUAL} \geq FB_{REQUIRED}$ (CONTAINS INTEGER X_{FB}) 2
NAVIGATION RESTRICTIONS	LENGTH	④	$L \leq L_{MAX}$
	BEAM	⑤	$B \leq B_{MAX}$
	DRAFT	⑥	$T \leq T_{MAX}$
INTERACTION WITH TERMINALS	PAYLOAD	⑦	$WP_{MIN} \leq WP \leq WP_{MAX}$
DATA RESTRICTIONS	TAYLOR SERIES	⑧	$.5 \leq V/\sqrt{L} \leq 1.2$
	T. S.	⑨	$.48 \leq CP \leq .70$
	T. S.	⑩	$3.25 \leq B/T \leq 3.75$
	T. S.	⑪	$CB = .925\ CP$

✻ REFER TO DETAILED CALCULATION IN APPENDIX E

7 CONTINUOUS VARIABLES (Δ, L, B, T, D, CP, V)

3 INTEGER VARIABLES (X_{PP}, X_{FB}, X_{CO})

Figure 8

CHAPTER VII.

OPTIMIZATION TECHNIQUES

The optimization problem as stated in the last chapter is a mixed integer, non-linear, mathematical problem with some expressions not given in closed form. The relationships used to determine the powering requirements of the ship are a combination of working graphs and tables. The relationships between several decision variables are involved and any simplifying assumption necessary to obtain a closed form expression would introduce unacceptable errors. Without such a closed form solution, analytical solution techniques cannot be incorporated. For a survey of the approaches applied to this problem, see Appendix to Reference 51.

One method of determining the powering requirements for design alternatives has been tabulated in working graphs. The Taylor Standard Series of model tests is an example which presents the powering requirement as a function of five variables. (Displacement, beam to draft ratio, volumetric coefficient, and speed to the square root of length ratio). There have been attempts at determining the analytic form of the relationship, however, one or more of the independent variables are usually set equal to constant values. These

variables selected are indicative of a special type ship. Because the relationships are not available for containerships in general, these analytic forms were viewed as being too restrictive. The solution methodology used must be compatible with the data in its available format of graphs and tables. The identification of an objective surface is possible using the available information. Also the constraints can be readily evaluated. This situation suggests that some form of search routine will be able to locate the location of the optimal objective value which meets the constraints.

7.1 BASIC SEARCH ROUTINES

7.1.1 Random Search

The Random Seach Technique applied to the ship design process is covered by Mandel and Leopold.[10] The method involves searching each variable sequentially, each time sampling at random from the acceptable range of the variable. As the procedure progresses, the search is concentrated around the more attractive solutions. This results in the determination of a solution for the first stage. The process is iterative, it is started over many times, with the best solution of previous iterations being retained. However, there are drawbacks to its use. First, there is the large amount of computational effort required. Secondly, there is difficulty in identifying the feasible range for

each of the variables searched. It maps out the surface during the process which provides additional information to the designer. Unfortunately, its randomness makes it difficult for the designer to interact with the program. The random nature does, however, help to insure adequate coverage given enough iterations.

7.1.2 Climbing Techniques

The Hill Climbing Techniques employ the information gained from the gradient of the surface to determine the direction for the next move. This technique is often used in conjunction with other techniques which determine the distance to jump. The methods require an initial point and the derivatives at that point. The process is usually slow to converge due to possibility of rapid oscillation in the movement vector as the solution is approached. Problems due to special surface forms have been handled by variations of the technique. Many of these include systematic rotation of the coordinate axis.[11] The major difficulty with this technique for our application is the problem of keeping the search within the feasible region.

One method of insuring that the search remains in the feasible region is to impose severe penalties for violating the constraints. The Sequential Unconstrained method uses this barrier technique successfully as discussed in the next section.

7.2 SEQUENTIAL UNCONSTRAINED MINIMIZATION TECHNIQUE (SUMT)

Ref [15]

7.2.1. General

The name of this technique is very descriptive. It is a process which transforms the constrained problem into a sequence of more easily managed problems without constraints. The set of solutions to these problems possibly converge to the solution of the original, constrained problem. There is no single method of determining the sub-problems nor the associated solution method. Presented here is one method that has proven useful.

The SUMT is designed to solve the optimization problem:

$$\text{Minimize} \quad f(\bar{x})$$

$$\text{Subject to:} \quad g_i(\bar{x}) \geq 0 \qquad i = 1, 2, 3, \ldots, m$$

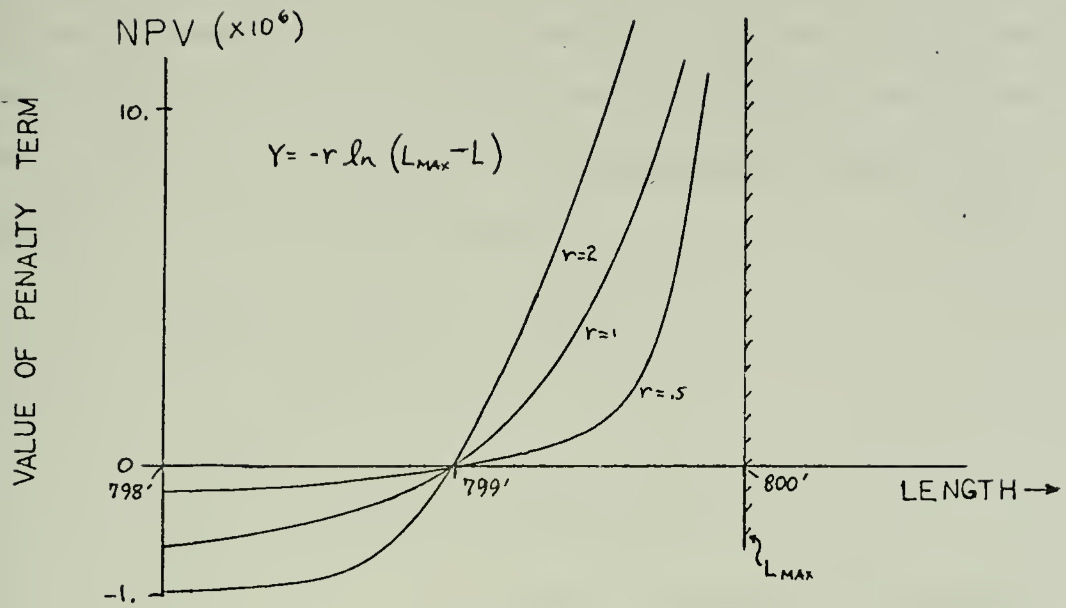
$$h_i(\bar{x}) = 0 \qquad i = m+1, m+2, \ldots, m+p$$

Where $\bar{X} = (x_1, x_2, x_3 \ldots, x_n)^T$ is a n-Dimension column vector.

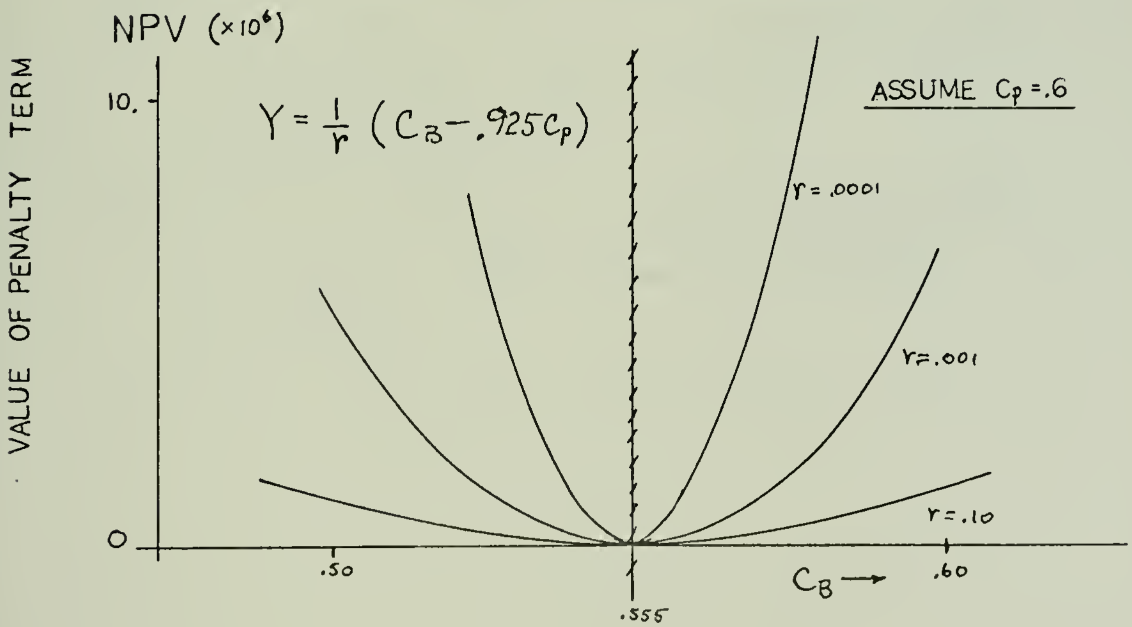
The technique applies a minimization method to a modified objective function P(x,r), where r is a given parameter.

$$P(\bar{x}, r) = f(\bar{x}) - r \sum_{i=1}^{m} \ln g_i(\bar{x}) + \sum_{i=m+1}^{m+p} \left[h_i(\bar{x})\right]^2 / r$$

From the function P(x,r) one can associate the additional terms to a penalty. Depending on the value of "r", the penalty takes different forms as illustrated in Figure 8. In the limit as "r" approaches zero, both penalty terms



INEQUALITY CONSTRAINT



EQUALITY CONSTRAINT

Figure 9

represent barriers. The systematic reduction of the value of the parameter "r" and the solution of the associated modified objective functions, under suitable conditions, will result in a sequence of minimums approaching the solution of the original problem.

$$\min_{\bar{x}} \quad P(\bar{x}, r) = \bar{X}'(r)$$

$$\lim_{r \to 0} \quad \bar{X}'(r) = \bar{X}^*$$

$$\lim_{r \to 0} \quad f[\bar{x}'(r)] = f[\bar{x}^*] = \mathcal{V}^*$$

WHERE $\mathcal{V}^*$ IS THE OPTIMAL SOLUTION TO THE PROBLEM.

The suitable conditions are as follows: [12]

(1) The feasible region is non-empty.

(2) $f(x)$ AND $g_j(x)$, $j = 1, 2, \ldots m$ are convex and continuous and $h_j(x)$, $j = m+1, m+2, \cdots m+p$ are linear function.

(3) For some constant K, the set $\{\bar{x} \mid f(\bar{x}) \leq K\}$ is bounded. (This prevents a "minimum at infinity")

(4) $P(\bar{x}, r)$ is strictly convex for all $r > 0$.

The objective surface of interest is not necessarily convex. This means that the results of the technique may be local optimums as opposed to a global solution. It must be emphasized that there is no guarantee of finding the problem solution in a single iteration. Additional runs with various starting positions would be necessary so that the characteristics of the surface could be fully explored. Only then would confidence in a single solution be justified. In this thesis, the application of the technique to a non-convex surface will be successfully demonstrated.

There are a variety of ways to implement the SUMT method. The one utilized here can be described as follows. Given a starting point, the method determines if the point is feasible. If not, the technique is applied to find such a point by using an objective function in the first phase which measures the degree of non-feasibility. After a feasible point is found, the value of the modified objective function P(x,r) the first, and the second derivatives with respect to the decision variables are determined at that point. The direction for the next move is calculated using the Newton-Raphson Method. If it is not possible to determine the inverse of the Hessian Matrix (See Page 69), the matrix of second partials is perturbed and a move is determined when the matrix inverse is able to be calculated. This results in an "Orthoginal Move" as identified in the

program. Once given the direction of the move, the Golden Section Search is employed to find an improved point in the move direction. This process is continued until the minimum of the program is found. This completes the first subprogram. Next the value of "r" is reduced and the process is repeated. This continues until the sequence of solutions converges. The result is the solution of the original problem with constraints.

In the next sections, the Newton-Raphson Method and Golden Section Search is discussed in more detail.

7.2.2 Newton Raphson Method Ref [52]

This method is used to identify the move vector. It is an indirect method for solving simultaneous non-linear equations. It utilizes the necessary condition for a point $\bar{x}^*$ to minimize a function Y(x). All the partial derivatives must disappear at that point.

$$Y_j'(\bar{x}^*) = 0 \qquad j = 1, 2, \ldots, n$$

The Newton-Raphson Method then solves the system of equations by using the derivative to estimate the functional value in the neighborhood of a point. This is done by performing for each equation a Taylor Series expansion of $Y_j'(\bar{x})$ about $\bar{x}^k$. If the higher order terms are ignored, the following equations are obtained.

$$Y_j'(\bar{x}^{k+1}) = Y_j'(\bar{x}^k) + \sum_{p=1}^{n} Y_{ip}''(\bar{x}^k)\left[x_{p,k+1} - x_{p,k}\right] \; ; \quad j = 1, 2, \ldots, n$$

where $\bar{x}^k = (x_{1,k} \, ; \, x_{2,k} \, ; \, x_{3,k} \, ; \, x_{4,k} \, ; \cdots \, x_{n,k})$

The determination of $\bar{x}^{K+1}$ requires the solution of these simultaneous equations. If we define the Hessian Matrix of second partial derivatives;

$$H(\bar{X}^K) \equiv H_K \equiv \begin{bmatrix} Y''_{11} & Y''_{12} & \cdots & Y''_{1n} \\ Y''_{21} & Y''_{22} & \cdots & Y''_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ Y''_{n1} & Y''_{n2} & \cdots & Y''_{nn} \end{bmatrix}$$

$$\text{WHERE} \qquad Y''_{ij} = \frac{\partial^2 Y(\bar{X}^k)}{\partial X_i \, \partial X_j}$$

THEN;

$$\bar{X}^{K+1} = \bar{X}^K - H_K^{-1} \cdot (\nabla Y(\bar{X}^K))^T$$

$$\text{WHERE} \qquad H_K^{-1} H_K = I, \quad \text{THE IDENTITY MATRIX}$$

For the determination of the move vector, we are interested in the direction along which to search for a better solution. The direction vector is defined by $-H_k^{-1} \cdot (\nabla Y(\bar{x}^k))^T$ for each step. The next step involves calculating the distance to move. The procedure is then repeated until the functional values of $Y_j'(\bar{x}^{k+1})$ become small. This process may not converge to a unique solution as seen by the graphic example given by Wilde and Beightler [13] in Figure 10. Assuming the system of equations has only one member, then this curve could represent the functional value of an equation. The roots or values of the independent variable X for which the function goes to zero is represented by the intersection of the curve and the X axis. In this case, there would be two possible solutions at points a & c. Depending on the starting position for the Newton-Raphson Method, the convergence to a root (solution) takes on different characteristics. The zones of definite, possible, or non-convergence are identified. The program using this technique identifies the non-convergence condition when it occurs.

7.2.3 <u>Golden Section Search</u> Ref [52]

The Golden Section Search is a method for determining the optimum of an objective function by successfully eliminating regions for investigation. This method is used to search along the direction determined by the Newton-Raphson Method to find the best solution. This new solution

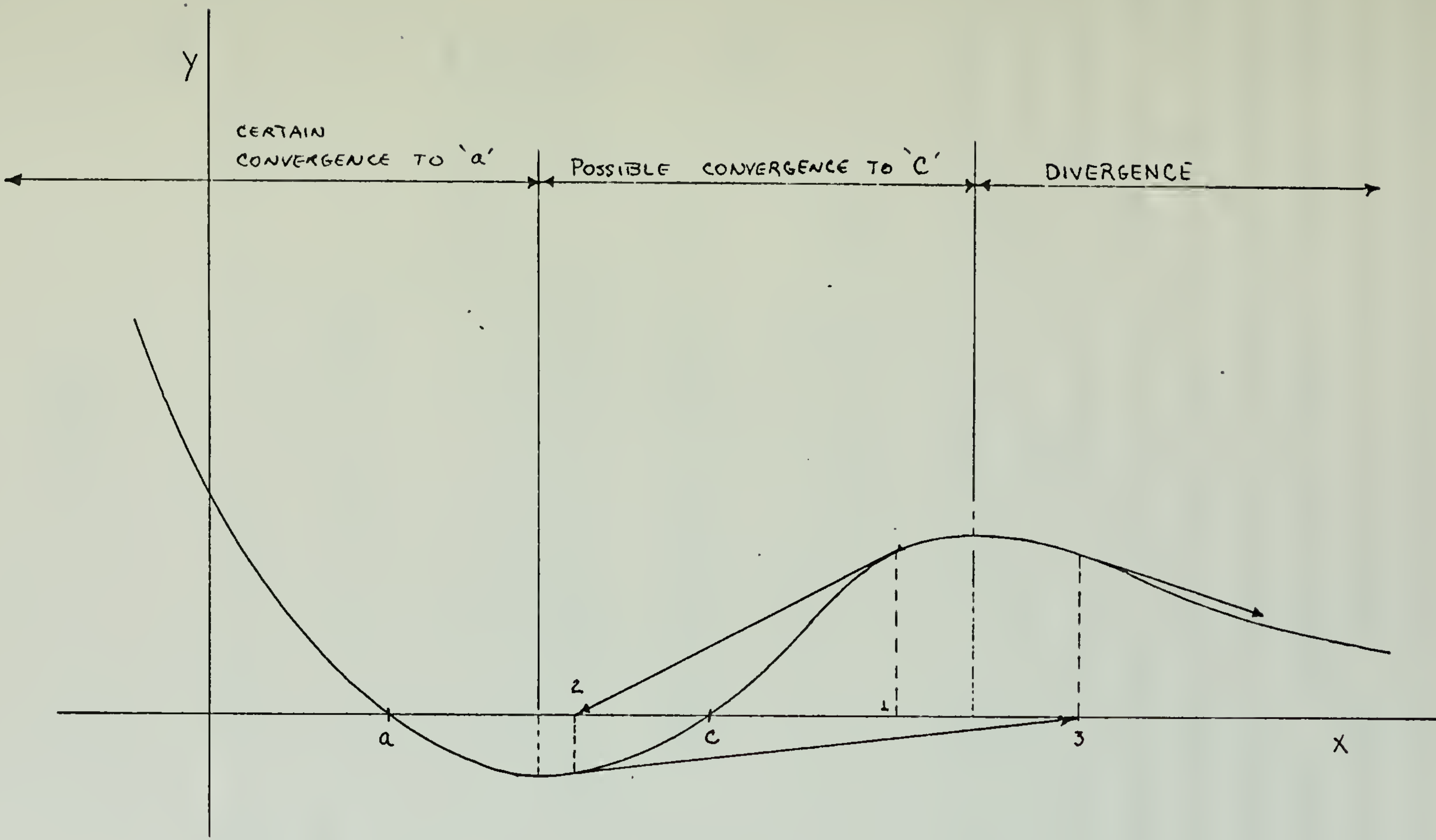


Figure 10 NEWTON-RAPHSON PROCEDURE
Ref [52]

point is then used as the starting point for the next iteration in the minimization of the objective. This method was originally designed to search a set interval. The SUMT program determines this interval in each case by searching along the vector until a functional value larger than the initial one is found. This defines the search interval. The upper bound f_u is determined by looking at successive points until a larger value than the initial one is found. The distance between successive points is taken as θ_u.

$$\theta_u^n = \sum_{i=0}^{n} (1.618)^i$$

then

$$f_u = f(\bar{X}_o + \theta_u^* \bar{S}) \geq f(\bar{X}_o)$$

where θ_u^* is defined with the smallest non-negative integer which satisfies the above equation and $\bar{S}$ is the unit vector in the move direction.

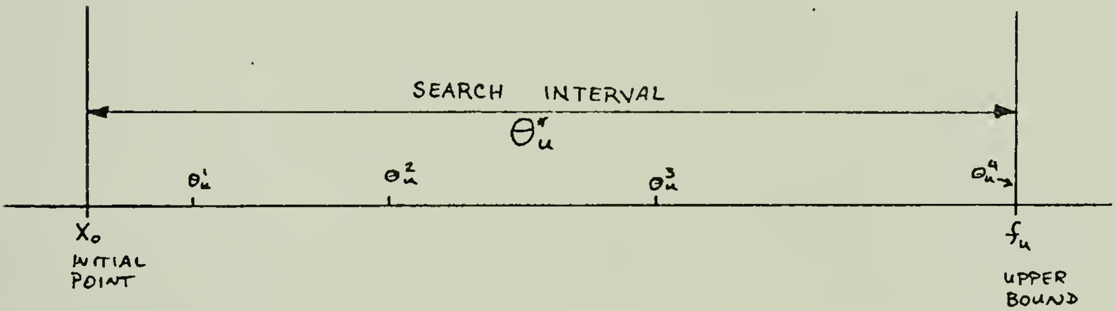
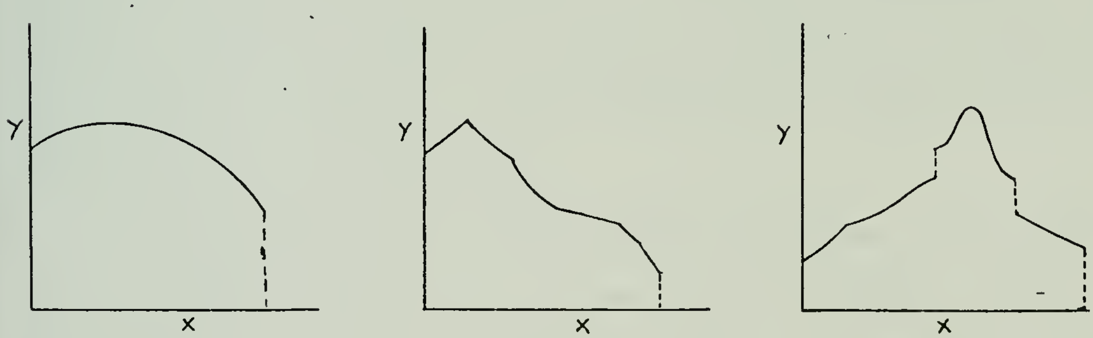


Figure 11

After the interval is defined, the search proceeds to determine the optimum value. This is accomplished by dividing the intervals into two parts and looking at the derivative at the intermediate position. This would indicate in which section the optimum would most likely occur. The process would continue until the optimum is found. The method which minimizes the number of iterations without additional information can be shown to be a method of partition which divides the remaining interval into sections of the ratio τ (1.618033989). This technique converges to a unique solution provided the objective function is strictly unimodal as defined by Wilde and Beightler.[14]

IF	$x_1 < x_2 < x^*$
THEN	$y_1 < y_2 < y^*$
WHEREAS, IF	$x^* < x_1 < x_2$
THEN	$y^* > y_1 > y_2$



(CONCAVE) (CONTINUOUS) (ARBITRARY)

Figure 12 UNIMODAL FUNCTIONS

7.3 SUMT COMPUTER PROGRAM

The optimization technique previously described has been programmed by the Research Analysis Corporation as outlined in Reference 16. This program requires that the user provide four subroutines. These include first a subroutine that reads in values as needed by the user in the other supplied subroutines; secondly, a subroutine which defines the value of the objective function and constraint functions; thirdly, a subroutine which determines the partial derivatives, and finally a subroutine which provides the second partial derivatives of the objective and constant functions.

The program was written with the capability of linear interpolating for the required first and second derivatives. This required that the objective function be developed from the design model. Such a routine would provide the required objective value for any value of the input variables. This routine thus describes the objective surface upon which the optimization technique would search and is used in the interpolation of derivatives.

The development of any objective routine must insure that for each combination of the input variables, there is defined only a single objective value. The program used defines several surfaces, one for each set of input parameters. The tabular inputs for powering calculations were

easily handled in this method. Simplified expressions for these would lead to the use of closed form expressions which could then be handled in other optimization techniques, one of which would be geometric programming as used in Reference 10. The model developed in the next chapter attempts to incorporate sufficient detail during a preliminary design stage so that the full capability of the SUMT optimization technique can be explored.

The program requires the selection of an initial starting point and various control parameters. The author's experience with these and other features are covered in the concluding chapter. The reader is directed to the user's manual, Reference 43. A complete explanation of this application of SUMT with input, set-up, and a sample run is covered in the Appendix.

CHAPTER VIII.

DEFINITION OF THE OBJECTIVE SURFACE

8.1 General

The strength of the search technique depends upon the explicit nature of the objective surface. The selection of the decision variables and design relationships has focused on the need to determine an explicit, single valued objective as a function of the decision variables. The general application of an optimization technique as described earlier in this paper requires the determination of such a surface. The actual surface defined is intended to be representative of an actual decision, however, the main interest here is in obtaining a model with which to test the optimization technique.

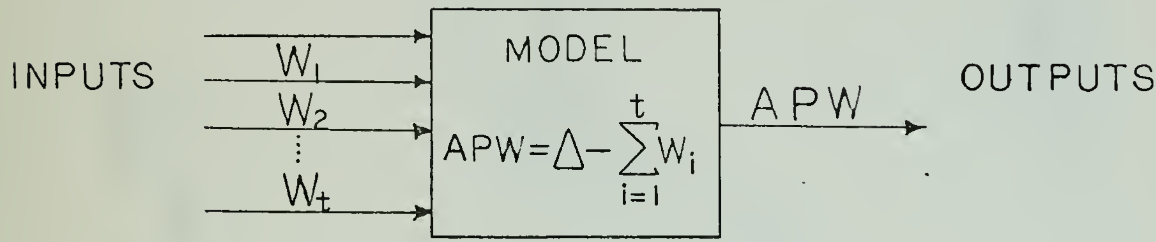
In this chapter, the containership design model which is used to determine the objective surface will be described. The actual relationships and other data used has been compiled in the Appendix. The methodology used to construct this model may assist in the understanding of its final form.

The first step involved defining a tentative set of variables. The decision variables introduced in Chapter V represent the primary, independent variables chosen. It would be possible to define the surface in terms of only these variables, but the complexity of the expressions would

lend the model awkward. Instead of following the usual procedure of introducing these new variables which are dependent upon the primary variables and then structuring the objective function in terms of these secondary variables, a more convenient method was used. This also helped to minimize the number of secondary variables defined. The transformation defining secondary variables were viewed as "black boxes" or subproblems. Often explicit relationships between the output and inputs were available. At other times, the relationships were given in terms of tables or graphs.

The construction of the model started at the end where the output objective was desired. Using the subproblem technique, the model was built up from the objective end. This systems approach facilitated the model construction. As subproblems were defined, their inputs became outputs of the next generation of subproblems. The goal in defining the subprograms was to determine the inputs necessary and the relationships required to obtain a simple and single valued relationship with the required output. It was found efficient to make extra subproblems whenever the relationships between the variables could not be expressed in a simple, single, closed form algebraic expression. This would provide the definition of new variables. Another advantage of proceeding in this manner would be the capability of having several groups working simultaneously on the

model after the first few steps. The assignment of subproblems should prove to be manageable in a real design effort. The following black box exemplifies the subproblem technique.



The process culminates when inputs to all the subroutines are either the primary decision variables or outputs from other subroutine. Only as the process is near completion can the final set of decision variables be identified.

The following block diagram depicts a single design iteration. The diagram represents only a small part of the total computerized program. It shows the development of the objective surface in terms of the design variables. The output of the program is then used in conjunction with the SUMT to obtain new solution points as shown diagramaticly by the feedback loop. Even though the Net Present Value objective was selected, it would be a simple matter to change to some other objective for the problem. See Appendix A for definitions.

The relationships that are used in the black boxes can be found in Appendix E by their assigned number. The program was designed so that the user could substitute other relationships.

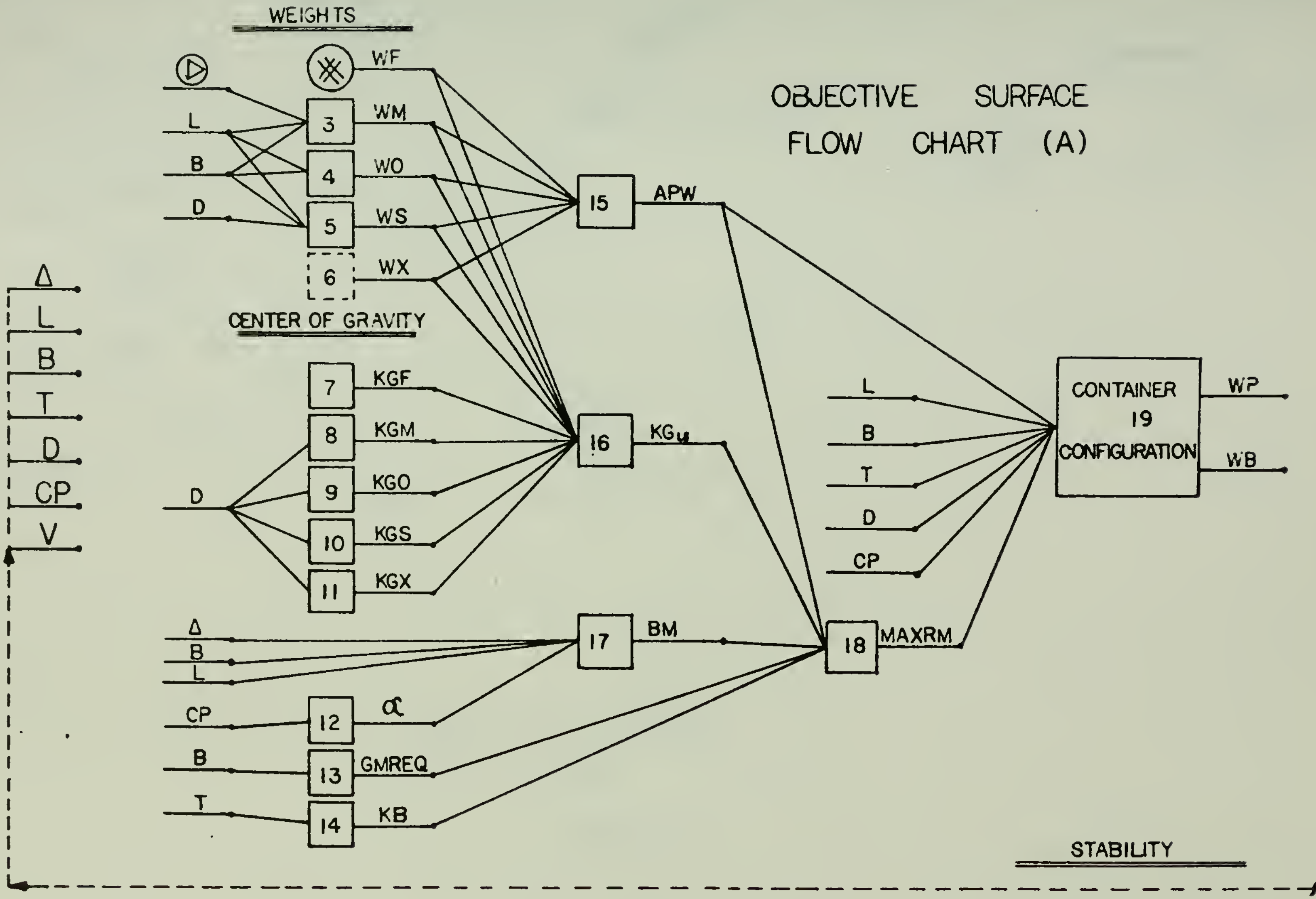
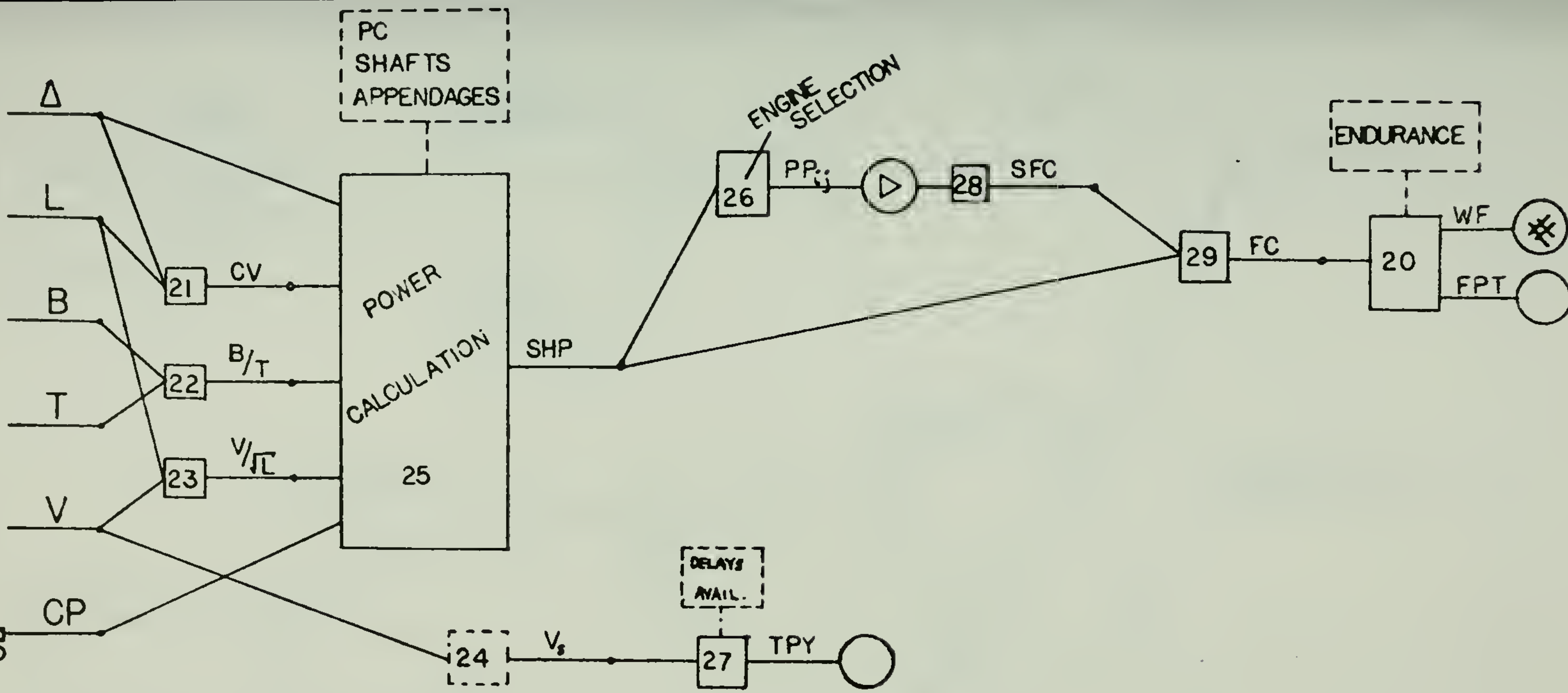
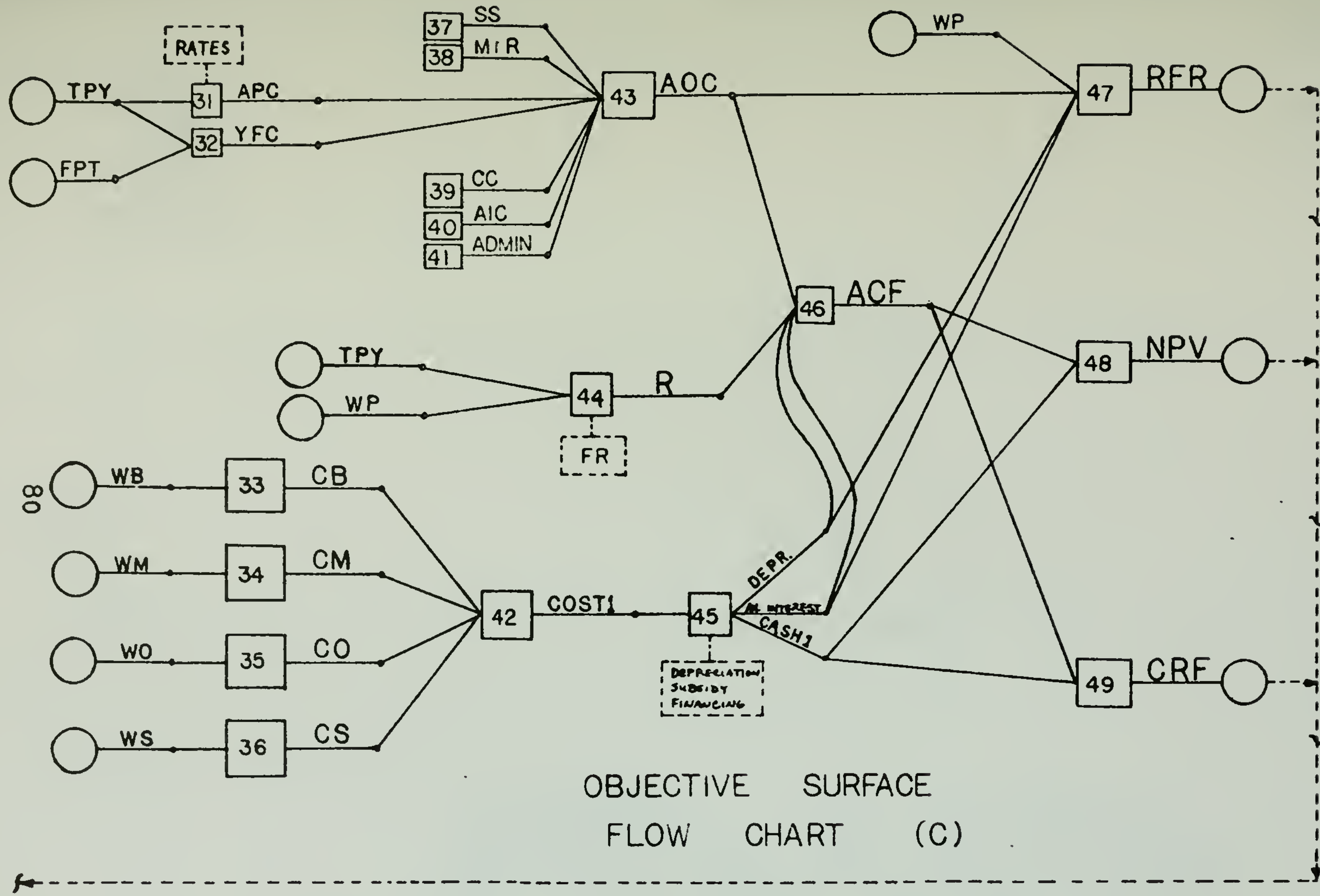

OBJECTIVE SURFACE
FLOW CHART (A)
WEIGHTS
WF
WM
WO
WS
WX
3
4
5
6
L
B
D
CENTER OF GRAVITY
7
8
9
10
11
KGF
KGM
KGO
KGS
KGX
15
APW
16
KGu
17
BM
12
13
14
α
GMREQ
KB
CP
T
Δ
18
MAXRM
CONTAINER
19
CONFIGURATION
WP
WB
V
STABILITY

Figure 13



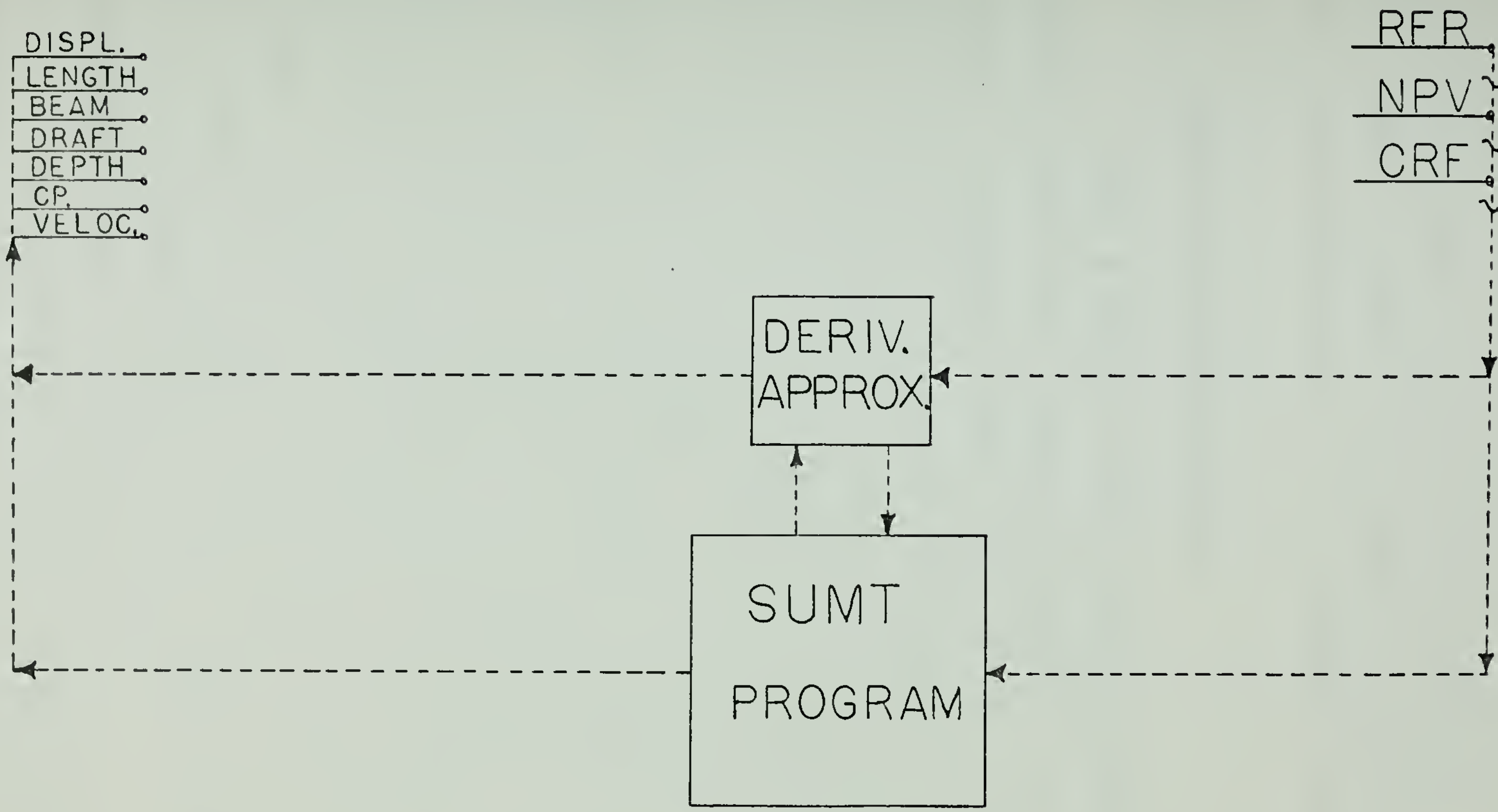
OBJECTIVE SURFACE
FLOW CHART (B)

Figure 14



OBJECTIVE SURFACE
FLOW CHART (C)

Figure 15



FEEDBACK LOOP SHOWING
INTERACTION BETWEEN SUMT
AND THE SHIP DESIGN MODEL

Figure 16

There are three blocks in the flow graph that require extensive calculations and additional explanation. These are the blocks which determine the required propulsive power, the power plant selection, and the container configuration.

8.2 Required Propulsive Power

Given a specific ship's form, methods have been developed to predict the required propulsive power to drive the vessel at different speeds. The process involves the use of model tests and correlations involving past design experience. The best approximation requires that a separate model be tested for each design alternative investigated. This is too expensive a procedure to follow when there are several different alternative geometries. Over the years, systematic studies of the resistance properties of ships have been conducted. These have resulted in several hull forms being tested and the results compiled in working graphs. Each of these series of tests typically limited the number of independent variables by fixing the value of one or more shape coefficients. It should be obvious that the use of any one series to determine the power requirement for an alternative would be only an approximation if the geometry of the design does not match that of the model series.

In the program developed, the Taylor Standard Series was used. In this series, the relationship between two of

the decision variables is fixed. For the Taylor Standard Series, the block coefficient is related to the prismatic coefficient as follows:

It was found necessary to impose this as a restriction in the mathematical model because of the strong relationship between the block form and the revenues generated by the design. When this constraint was not imposed, the program would select a box shaped midship section to house the containers. The resulting changes in powering requirements could not be calculated using the series data. Even if another series were used instead of the Taylor Standard Series, the program would experience similar difficulties with other pairs of decision variables. This constraint reduced the number of decision variables by one.

8.3 Discrete Power Plant Selection

This model assumes that given a required SHP, a preferred engine configuration can be identified. The problem of discrete power plants experienced with gas turbines has been incorporated into the program. Because the speed and distance values remain constant for the selection, the gas turbine engine alternatives are ordered according to their initial cost and specific fuel consumption. An engine configuration is identified by the number of gas turbines installed. In this problem the GE built L.M. 2500 is used. As the SHP increases, there may be discontinuities

in costs. Because the gas turbine is available only in discrete sizes, there exists many situations in which the installed turbines may not be operating at maximum rated power. The following decision rule is proposed for the selection of the number of gas turbines for installation.

It is assumed that the initial cost of the power plant monotonically increases with the SHP required (See Figure 21). The variables cost for fuel varies proportionally to SFC for a fixed required SHP (See Figure 22). Because of the nature of gas turbines, their SFC decreases monotonically as the power output is increased. It is, therefore, desirable to install turbines that operate near full power. It is assumed for this model that the best engine configuration is the one that is just able to meet the SHP requirement. Any combination calling for fewer engines cannot provide the power required and is thus non-feasible. A combination that operates extra engines will run at lighter loads and thus at a higher SFC. The desire of minimizing initial fuel costs associated with the power plant selection is consistant with this decision rule. This ignores the change in maintenance costs with the variation in engine loading.

Past history has demonstrated the reliability of gas turbines and it compares with other types of propulsion units. Typically more units have been designed into the plant as reserve power sources. This increases the reliability of the

total system at an increase in cost. This model permits the designer to require additional standby units as desired.

8.4 Payload Configuration

There are two steps in determining the configuration of the containers carried on board a ship. The first determines the available space and weight available for the payload. The second determines the loading so as to meet the weight and stability requirements. This reduced the number of constraint programs.

The space is determined by obtaining the maximum dimensions of the available space for the containers, then dividing the ships into decks. The weight available for the payload is determined by incorporating Archimedes Principle. The payload and ballast weights must equal the difference between the displacement weight and the sum of the other weights previously determined. The program then loads each deck sequentially until one of the constraints is met. The number of containers per deck is calculated as follows. The containers carried on decks below the waterline were treated together and assumed to have a shape factor relating directly to the ship block coefficient. For those containers carried above the waterline and above the main deck, each level was considered to have a shape factor equal to the coefficient of the water plane area. The program assumes that the coefficient of the

water plane area can be expressed as a function of the prismatic coefficient. The shape factor is used to determine space for containers on each level by multiplying the shape factor by the dimensions of the cargo space.

The model test for the stability constraint uses a calculation of the available weighted moment at the designed displacement. The program starts by placing all of the available weight as ballast in the double bottom of the ship without regard to space limitations. This automatically insures that the weight requirement is met. If this results in a feasible solution, that is, if the non-linear stability constraint is not violated, then small increments of weight are removed from the ballast location and placed in the form of containers in the cargo hold. The only change in the weighted moment would then be due to the movement of the weight in the form of ballast in the double bottom to a position at some higher position that would correspond to the position of a container. This process is continued sequentially until the actual full load GM is reduced to 5 per cent of the beam or one of the restrictions is encountered resulting from stacking the containers. For ease of calculation, the model groups the containers. Each deck is filled one tenth at a time. The program starts with the lowerst possible level and fills each deck sequentially. The model will stack containers external to the main deck. The

designer can limit the number of levels in this configuration. The sample problem assumes that the maximum number of containers that can be stacked is six. This is consistant with the ASA requirements for this size container. Also, the number of levels above the main deck was limited to two.

8.5 Input Parameters

Associated with many of the subproblems shown in the flow chart are parameters that must be provided to complete the calculations. These constants may be supplied by the program user. The input parameters are listed in Table 4. The adjustment of these parameters permit the designer to approach the real design problem and to introduce the effects of other criteria expressed by the ship owner.

The ship availability refers to the per cent of time that the ship will be operational. The design and cost weighting factors are provided to permit the user to modify the equations used in the computer program.

Table 4

PROGRAM INPUT PARAMETERS

PARAMETER	SYMBOL	VALUE
DESIGN PARAMETERS		
PROPULSIVE COEFFICIENT	PC	
ENDURANCE	E	
DISTANCE BETWEEN PORTS	DBP	
SHIP AVAILABILITY	AVAIL	
NUMBER OF SHAFTS	NSHAFT	
MIN. NO. OF ENGINES*	NENGU	
NO. OF SPARE ENGINES	NEXTRA	
MAX. PAYLOAD WT.	WW	
MIN. PAYLOAD WT.	WPMIN	
MAX. CONTAINER STACKING	ND	
MAX. STACKING ABOVE DK.	MD	
AVERAGE CONTAINER WT.	WC	
EFFECTIVE CONT. LENGTH	ELENGT	
EFFECTIVE CONT. WIDTH	EWIDTH	
EFFECTIVE CONT. DEPTH	EDEPTH	
DOUBLE BOTTOM HEIGHT	DOUBLE	
BALLAST WEIGHT KG.	KGB	
MAX. SHP FOR SINGLE ENG.	SHPM	
SEA SPEED FACTOR	BETA1	
SFC FACTOR	BETA2	
MISC. WEIGHT	WXX	
MISC. WEIGHT KG.	XKGX	
DESIGN WEIGHTING FACTORS		
FACTOR FOR OUTFIT WT.	WWO	
FACTOR FOR STEEL WT.	WWS	
FACTOR FOR MACHINERY WT.	WWM	

* NEGATIVE VALUE INDICATES STEAM TURBINE PROPULSION.

Table 5

PROGRAM INPUT PARAMETERS

PARAMETER	SYMBOL	VALUE
NAVIGATION CONSTRAINTS		
MAX. LENGTH	LENGTM	
MAX. BEAM	BEAMM	
MAX. DRAFT	DRAFTM	
ECONOMIC PARAMETERS		
FREIGHT RATE	FR	
PORT CALL FEE	PCF	
DAILY PORT FEE	DPF	
PRICE OF FUEL	PRICE	
ANNUAL INSURANCE RATE	AIR	
ASSET LIFE	NN	
SALVAGE VALUE	SV	
DISCOUNT FACTOR	DF	
SUBSIDY RATE	SUSIDR	
PERCENT FINANCED	PF	
INTEREST RATE	RATE	
CORP. TAX RATE	CTR	
INVESTMENT TAX CREDIT	AITC	
COST WEIGHTING FACTORS		
FACTOR FOR OUTFIT COST	CCO	
FACTOR FOR STEEL COST	CCS	
FACTOR FOR MACHINERY C.	CCM	
PROGRAM PARAMETERS		
OBJECTIVE SELECTION	IOBJ	
CONSTRAINT SENSITIVITY PARAMETERS	DELTA(I)	

CHAPTER IX

ANALYSIS

Responding to the needs of the owner as outlined earlier, the optimization techniques are applied to the ship design model. The results of the investigation are presented to demonstrate the capabilities of the computer programs. Prior to discussing the actual problem solution, an attempt was made to validate the design program by comparing the program results with three containership designs.

9.1 Program Validation

The design program was used to develop details of three separate preliminary containership designs. The first design was developed by George G. Sharp, Company, during the evaluation of gas turbine power plants. The remaining two designs are products of the Maritime Administration CMX Project. The designs were developed separately by Bath Iron Works and the Newport News Shipbuilding and Dry Dock Company. The following tables indicate the similarity in results. In each case the design program was given the principle dimensions of the ship. The input parameters used in each of the designs corresponded to the values obtained from the respective preliminary designs.

Table 6

MODEL VALIDATION

VARIABLES	G.G. SHARP	MODEL
DISPLACEMENT	30659	30659
LENGTH	752	752
BEAM	93	93
DRAFT	27.3	27.3
DEPTH	55.0	55.0
PRISMATIC COEF.	.65	.65
BLOCK COEF.	.561	.60
VOLUME COEF.	.0025	.0025
VELOCITY	25.8	25.7
FUEL WT.	2470	3035
MACH. WT.	1123	1124
OUTFIT WT.	1659	1560
STEEL WT.	9020	8716
MISC. WT.	268	300
BALLAST WT.	0	1286
PAYLOAD WT.	15375	14637
GM	1.73	8.1
NO. CONTAINERS	751	714
TOPSIDE	NA	3
BELOW DECK	NA	6
NO. SHAFTS	2	2
TPY	NA	17.5
SHP REQ	55500	55640
COST1	25.58	20.45
AOC	2.5 †	4.14 ‡
RFR	NA	20.5
CRF	NA	.50
FR	NA	50.
NPV	NA	19.58
	1	1

† INCLUDES FUEL OIL ONLY

‡ REFLECTS A LOW PRICE IN FUEL ENTERED IN ERROR

Table 6

MODEL VALIDATION

VARIABLES	NEWPORT NEWS	MODEL	BATH IRON WORKS	MODEL
DISPLACEMENT	32200	32200	31170	31170
LENGTH	696	696	645	645
BEAM	103	103	86	86
DRAFT	29.5	29.5	31.5	31.5
DEPTH	60	60	54.8	54.7
PRISMATIC C.	.548	.548	.639	.639
BLOCK COEF.	.532	.532	.624	.624
VOLUM. COEF.	.0033	.0033	.004	.004
VELOCITY	23.3	23.3	20.4	20.4
FUEL WT.	3300.	3425	3510	3718
MACH. WT.	1112.	1282	NA	10732
OUTFIT WT.	1853.	1630	NA	3602
STEEL WT.	9125.	8945	NA	6859
MISC. WT.	423.	300	NA	300
BALLAST WT.	367.	1580	~3600 ⊙	5000
PAYLOAD WT.	16020	15038	NA	10610
GM	2.4	6.25	NA	4.37
No. CONTAINERS	1350	1268	922	923
TOPSIDE	2	3	2	3
BELOW DECK	7	7	6	6
No. SHAFTS	1	1	1	1
TPY	NA	15.84	NA	14.34
SHP REQ.	35000	35400	24000	24700
COST1	NA	18.1	NA	22.4
AOC	NA	4.1	NA	4.5
RFR	NA	21.4	NA	37.93
CRF	NA	.51	NA	.14
FR	NA	50.	NA	50.
NPV	NA	17.6	NA	4.9
	2	2 ‡	3	3

‡ LIMITED BY STACKING
⊙ BALLAST WEIGHT FOR SHORTER VERSION
NA ≡ NOT AVAILABLE

9.2 Program Inputs

The application of the decision model to the scenario requires several input parameters. Unless otherwise stated, these parameters were used for each of the designs analized. The parameters are categorized as either design, economic or financial. The design parameters include the assumptions necessary to determine the ship design as well as several of the constraint values. The economic parameters cover the various costs and revenues generated by the design. The financial parameters relate to other economic aspects that indirectly relate to cost by indicating the owner's preferences. Table 18 gives the values of the coefficients used in the sample problem.

9.3 Procedure

The application of the minimization technique requires the identification of a starting position from which to search the objective surface. The primary concern is to start each search with a feasible solution to the problem. From this point, the SUMT Program will take over the procedure and then locate a local optimum. Because the objective surface is not always convex over the feasible domain, other starting points or solutions may result in the search culminating at different local optimums. The concern is then to start the

program a sufficient number of times, at different locations so that the surface characteristics can be deduced and the best local optimum can be taken as a solution to the problem at hand.

The procedure was to select four starting solutions, each different, so that the total search would encompass most of the feasible surface. The first starting point, which is labeled Alternative 2 on the next page, represents a modification of a design used by George G. Sharp Company. This alternative has similar characteristics of the actual design which is shown as Alternative 1. The major difference is in the number of shafts in the design.

The second starting solution was chosen with a higher displacement. Alternative 3 was used for a starting point even though it had been an output of a previous optimization. The third and fourth starting points, double and single shaft arrangement for a smaller ship. They are shown as Alternatives 5 and 7.

The remaining alternatives show the results obtained. Not shown are two attempts to start the program at nonfeasible initial positions on the surface. This resulted in an unsuccessful attempt by the program to find a feasible starting point. For the nonfeasible alternatives, the measure of effectiveness was most easily minimized by reducing the size of the design. No revenues were generated to

IDENTIFICATION OF ALTERNATIVES

ALTERNATIVE / VARIABLES	1	2	3	4
DISPLACEMENT	30,659.	30,659.	39,641.	45310.
LENGTH	750.	750.	723.	761.
BEAM	93.	93.	94.1	98.4
DRAFT	27.3	27.3	32.2	33.4
DEPTH	55.	55.	58.7	59.6
PRISMATIC CO.	.65	.65	.69	.69
BLOCK COEF.	.56	.56	.63	.63
VOLUM. COEF.	.0026	.0025	.0036	.0036
VELOCITY	25.7	25.7	22.8	23.7
FUEL WT	6666.3	7179.1	5760.2	7013.7
MACH. WT.	1070.3	1147.3	964.7	1128.7
OUTFIT WT.	5330.2	5330.2	5121.9	5971.1
STEEL WT.	8715.9	8715.9	8666.3	9583.
MISC. WT.	300.	300.	300.	300.
BALLAST WT.	22.6	145.7	265.2	2024.9
PAYLOAD WT.	8553.6	7840.8	18,562.	19,288.
GM	15.5	16.1	4.86	8.09
NO. CONTAINERS	518	475	1125	1170
TOPSIDE	0	0	2	2
BELOW DECK	5	4	6	6
NO. SHAFTS	1	2	2	2
NO. ENGINES	3	4	2	4
SHP REQ.	57,231.	61,634.	45,377.	56,800
COST 1	31.26	32.66	29.38	36.66
AOC	10.97	12.22	9.98	12.11
RFR	82.37	100.65	38.33	43.70
CRF	.13	(−)*	.74	.57
FR	100.	100.	100.	100.
NPV	10.48	(−)*	48.08	51.90
PROGRAM	NA.	INPUT	OUTPUT/INPUT	OUTPUT

* (−) INDICATES NAGITIVE VALUE

Table 7

IDENTIFICATION OF ALTERNATIVES

ALTERNATIVE / VARIABLES	5	6	7	8
DISPLACEMENT	15,000.	22,771.	15,000.	28,384.
LENGTH	600.	674.	600.	670.
BEAM	80.	78.2	80.	79.2
DRAFT	25.0	28.4	25.0	32.6
DEPTH	45.	45.	45.	49.8
PRISMATIC CO.	.60	.60	.60	.62
BLOCK COEF.	.44	.53	.44	.57
VOLUM. COEF.	.0024	.0026	.0024	.0033
VELOCITY	20.0	20.0	20.0	20.5
FUEL WT.	1,958.7	2,378.8		2,900.4
MACH. WT.	843.6	855.1		870.8
OUTFIT WT.	2,934.3	3,405.1		3,446.5
STEEL WT	5,466.4	6,171.4		6,475.0
MISC. WT.	300.	300.		300.0
BALLAST WT.	28.7	1.4		2,164.7
PAYLOAD WT	3,468.3	9,659.0		12,226.0
GM	14.5	5.6		4.46
NO. CONTAINERS	210	585		740
LEV. TOPSIDE	0	1		2
LEV. BELOW DECK	3	5		5
NO. SHAFTS	2	2	1	1
NO. ENGINES	2	2	2 *	2*
SHP REQ.	13,929.	16,917		21,000.
COST 1	20.0	22.02		24.51
AOC	5.2	5.60		6.51
RFR				
CRF				
FR	100.	100.	100.	100.
NPV	(−)	11.75	(−)	27.8
PROGRAM	INPUT	OUTPUT	INPUT	OUTPUT

* USER FORCED EXTRA ENGINE FOR RELIABILITY.

(−) INDICATES NEGATIVE VALUE

Table 7 (cont.)

counteract this tendency. Suggestions for future modifications are covered in the concluding chapter.

9.4 SUMT Trajectories

The following tables show the trajectories followed during the search by the SUMT program. The starting point and program optimum alternatives are given in terms of the decision variables. The intermediate solutions are shown by the incremental differences resulting in the changes between successive steps. The tables also indicate which constraints are constraining the solutions. These intermediate solutions represent the solution for each of the subproblems associated with the successively decreasing value of the program parameter 'r'.

Most of the improvements in the objective seem to occur in the first few iterations. This indicates that the process could be streamlined by imposing looser convergence criteria. This would permit the program to terminate its search earlier. It would not be necessary for the penalty terms introduced in the modified problem to be diminished by an even further reduction in the parameter 'r'. The execution times for the optimization procedure are given for each of the problems. The comparison between results is not possible here. The differences in the objective function result from various freight rates used. The final table of comparisons account

SOLUTION TRAJECTORY

ALTERNATIVE 2 → 3

DESIGN VARIABLES		STARTING POINT	CHANGE IN VALUE IN SUBPROBLEM NO. 1	2 ‡	3	4	FINAL POSITION
DISPLACEMENT		30,659.	+ 8,990.	− 8.			39,641
LENGTH		750.	− 19.	− 8.			723.
BEAM		93.	+1.	+ .1			94.1
DRAFT		27.3	+4.	+ .9			32.2
DEPTH		55.	+ 3.	+ .7			58.7
PRISM. COEF.		.65	+.04	—			.692
VELOCITY		25.7	− 2.8	−.1			22.8
CONSTRAINT VALUES	TIME (SEC)	1.010	12.390	14.050			14.050
FREEBOARD ($\geq FB_{REQ}$)							
STRENGTH ($L/D \leq 15.$)							
MAX. LENGTH (900)							
MAX. BEAM (110.)							
MAX. DRAFT (37)							
MAX. $V/\sqrt{L}$ (1.2)							
MIN. $V/\sqrt{L}$ (.5)							
MAX. CP (.70)			TIGHT	TIGHT			TIGHT
MIN. CP (.48)							
MAX. B/T (3.75)							
MIN. B/T (2.25)							
MAX. CV (.006)							
MIN. CV (.001)							
CB ≤ .925 CP			TIGHT	TIGHT			TIGHT
OBJECTIVE * ($NPV \times 10^{-6}$)		35.88	+ 89.0	+ 5.			129.88

‡ SOLUTION CONVERGED AT THE END OF SUBPROBLEM #2.

(—) INDICATES NO CHANGE

* FR = $200./TON

Table 8

SOLUTION TRAJECTORY ALTERNATIVE 3 → 4

DESIGN VARIABLES		STARTING POINT	CHANGE IN VALUE IN SUBPROBLEM NO. 1	2	3	4	FINAL POSITION
DISPLACEMENT		39,640.	+5660	—	+10.	—	45,310
LENGTH		723.0	+38.	–	–		761.
BEAM		94.1	+4.3	+.1	–		98.5
DRAFT		32.2	+1.26	—	—	—	33.4
DEPTH		58.7	+ .86	—	—	—	59.5
PRISM. COEF.		.692	—	—	—	—	.692
VELOCITY		22.8	+.9	—	—	—	23.7
CONSTRAINT VALUES	TIME (SEC)	.960	4.460	5.490	6.460	8.270	8.270
FREEBOARD ($\geq FB_{REQ}$)							
STRENGTH ($L/D \leq 15.$)							
MAX. LENGTH (900)							
MAX. BEAM (110.)							
MAX. DRAFT (37.)							
MAX. $V/\sqrt{L}$ (1.2)							
MIN. $V/\sqrt{L}$ (.5)							
MAX. CP (.70)		TIGHT	TIGHT	TIGHT	TIGHT	TIGHT	TIGHT
MIN. CP (.48)							
MAX. B/T (3.75)							
MIN. B/T (2.25)							
MAX. CV (.006)							
MIN. CV (.001)							
CB ≤ .925 CP		TIGHT	TIGHT	TIGHT	TIGHT	TIGHT	TIGHT
OBJECTIVE * ($NPV \times 10^{-6}$)		\$126.2	+11.4	+0.	+0.	+0.	137.6

* FR = \$200./TON

(–) INDICATES NO CHANGE

Table 9

SOLUTION TRAJECTORY

ALTERNATIVE (5) → (6)

DESIGN VARIABLES		STARTING POINT	CHANGE IN VALUE IN SUBPROBLEM NO. 1	2	3	4	FINAL POSITION
DISPLACEMENT		15,000.	+7,160.	-1,860.	+2,480.	-9.	22,771.
LENGTH		600.	+3.	+1.	+70.	—	674.
BEAM		80.	+0	-1.9	+.1	—	78.2
DRAFT		25.	+5.2	-1.8	+0	—	28.4
DEPTH		45.	+0	+0	+0	—	45.
PRISM. COEF.		.60	—	—	—	—	.60
VELOCITY		20.0	—	—	—	—	20.0
CONSTRAINT VALUES	TIME (SEC)	.980	7.620	10.110	12.500	13.370	13.370
FREEBOARD ($\geq FB_{REQ}$)						TIGHT	TIGHT
STRENGTH ($L/D \leq 15.$)						TIGHT	TIGHT
MAX. LENGTH (900)							
MAX. BEAM (110.)							
MAX. DRAFT (37.)							
MAX. $V/\sqrt{L}$ (1.2)							
MIN. $V/\sqrt{L}$ (.5)							
MAX. CP (.70)							
MIN. CP (.48)							
MAX. B/T (3.75)							
MIN. B/T (2.25)							
MAX. CV (.006)							
MIN. CV (.001)							
$CB \leq .925\ CP$							
OBJECTIVE* ($NPV \times 10^{-6}$)		3.56	+27.1	+1.6	+5.2	+0.	37.4

* FR = $200./TON

(–) INDICATES NO CHANGE

Table 10

SOLUTION TRAJECTORY

ALTERNATIVE 7 → 8

DESIGN VARIABLES	STARTING POINT	CHANGE IN VALUE IN SUBPROBLEM NO. 1	2 ‡	3	4	FINAL POSITION
DISPLACEMENT	15,000.	+13,384.	—			28,384.
LENGTH	600.	+70.	—			670.
BEAM	80.	−1.	—			79.
DRAFT	25.	+7.6	—			32.6
DEPTH	45.	+4.7	—			49.7
PRISM. COEF.	.6	+ .08	—			.68
VELOCITY	20.0	+ .5	—			20.5
CONSTRAINT VALUES						
FREEBOARD ($\geq FB_{REQ}$)						
STRENGTH ($L/D \leq 15.$)						
MAX. LENGTH (900)						
MAX. BEAM (110.)						
MAX. DRAFT (37)						
MAX. $V/\sqrt{L}$ (1.2)						
MIN. $V/\sqrt{L}$ (.5)						
MAX. CP (.70)						
MIN. CP (.48)						
MAX. B/T (3.75)						
MIN. B/T (2.25)						
MAX. CV (.006)						
MIN. CV (.001)						
CB ≤ .925 CP			TIGHT			TIGHT
OBJECTIVE ($NPV \times 10^{-6}$)*	6.68	+ 47.64	+ .0			54.32

FR = $150./TON

(—) INDICATES NO CHANGE

‡ SOLUTION CONVERGED AT END OF SUBPROBLEM #2.

Table 11

for these differences and presents the results based on a freight rate of $100/ton.

9.5 Ranking the Alternatives

After conducting the individual optimization problems with the various starting points, a comparison of results was desired so that the best design could be identified. The various alternatives were compared using three measures of the economic worth of the designs. The following table gives the Net Present Value of the design based upon $100/ton received in revenues. Also the Capital Recovery Factor based upon the total investment and the Required Freight Rate are listed. The RFR depicts the rate that must be charged by the operation of the ship so that the revenues would just cover his costs which include depreciation charges.

The matrix shows that no single ship is preferred using all these criteria. It also shows the improvement obtained in the measure of effectiveness using the SUMT Program. Alternatives 3 and 4 switch position in relative ranking as the objective is switched from NPV to CRF or RFR. The solution to the scenario with the given assumptions would be Alternative 4. Other scenarios may result in one of the other designs being a solution. Each of the designs carry a different payload. The differences in worth per ton transported is not so great which indicates that two smaller ships may be

RANKING OF ALTERNATIVES
BY VARIOUS CRITERIA

ALTERNATIVE	NPV ($\times 10^6$)	※	CRF	※	RFR	※
1 Δ = 30,659. 1 SHAFT	10.48	5	.13	5	82.37	5
2 Δ = 30,659. 2 SHAFTS	(−)		(−)		100.65	6
3 Δ = 39,641. 2 SHAFTS	48.08	2	.74	1	38.33	1
4 Δ = 45,310. 2 SHAFTS	51.90	1	.57	2	43.70	3
5 Δ = 15,000. 2 SHAFTS	(−)		(−)		123.49	7
6 Δ = 22,771. 2 SHAFTS	11.75	4	.37	4	47.92	4
7 Δ = 15,000. 1 SHAFT	(−)		(−)		—	
8 Δ = 28,384. 1 SHAFT	27.10	3	.48	3	42.80	2

※ INDICATES RELATIVE RANKING
(−) INDICATES NEGATIVE VALUE

Table 12

preferred over one larger ship. The increased flexibility available to the owner may make a number of small ships an attractive proposition.

9.6 Discontinuities

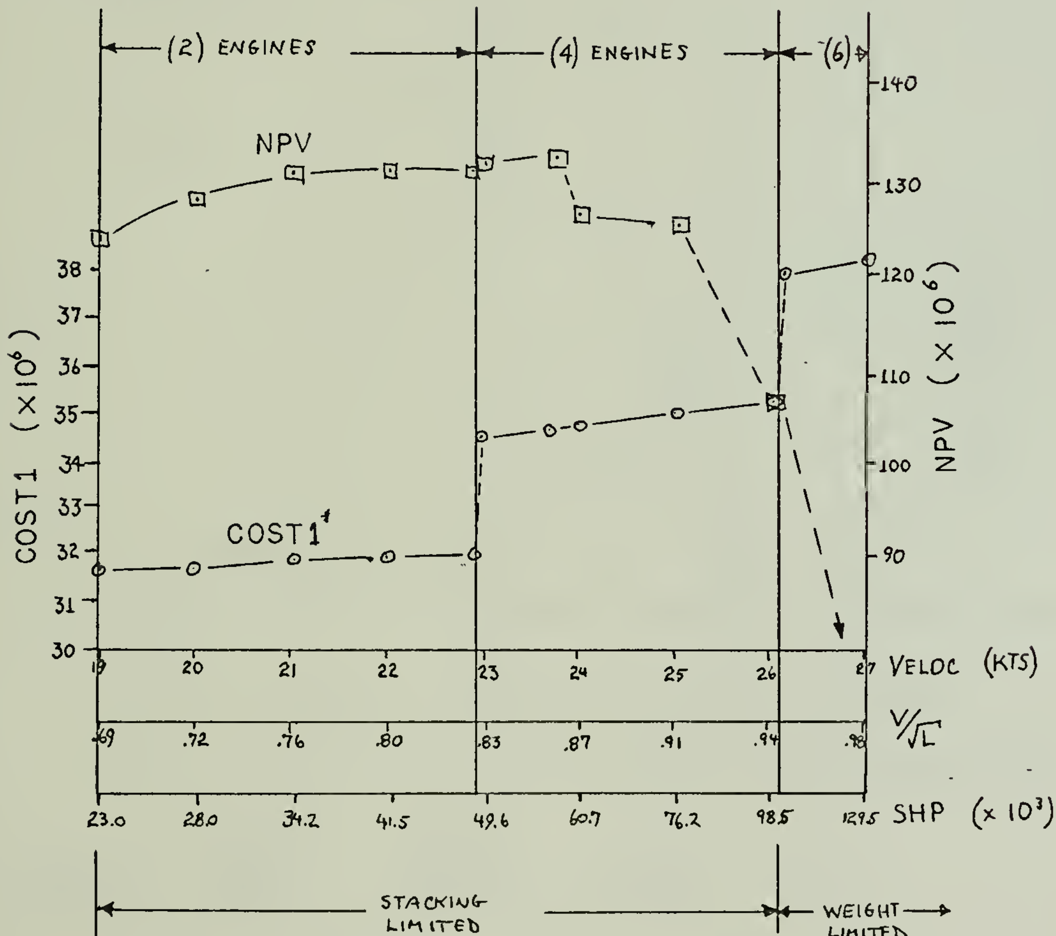
During the design of the various alternatives, discontinuities were observed in the objective surface. These were the direct result of the discrete characteristics of the engine and installed cargo. The following graphs show the effects of the discrete factors in the design and additionally show the performance of the search routine in the neighborhood of the discontinuity. In order to demonstrate these factors, the ship hull design associated with design Alternative 4 was held constant as the design speed was varied from nineteen to twenty-seven knots. This provided a profile of the objective surface along a single dimension. A similar graph is also developed for Alternative Number 3.

The effects of the discrete power plants are evident as the speed is increased. The graphs note the speeds at which additional engines are required. The cost function reflects the additional costs involved in the transition. In the graph for Alternative 4, the quantum drop in the objective function just before twenty-four knots is due to the cargo capacity lost when the engine box was enlarged. The same integer number of containers could no longer fit in the length available

OBJECTIVE SURFACE PROFILE
FOR DESIGN ALTERNATIVE FOUR

SHIP GEOMETRY	
Δ	45,310. TONS
L	761.′
B	98.4′
T	33.4′
D	59.6′
CP	.69
2 SHAFTS	

FR = $200. / TON



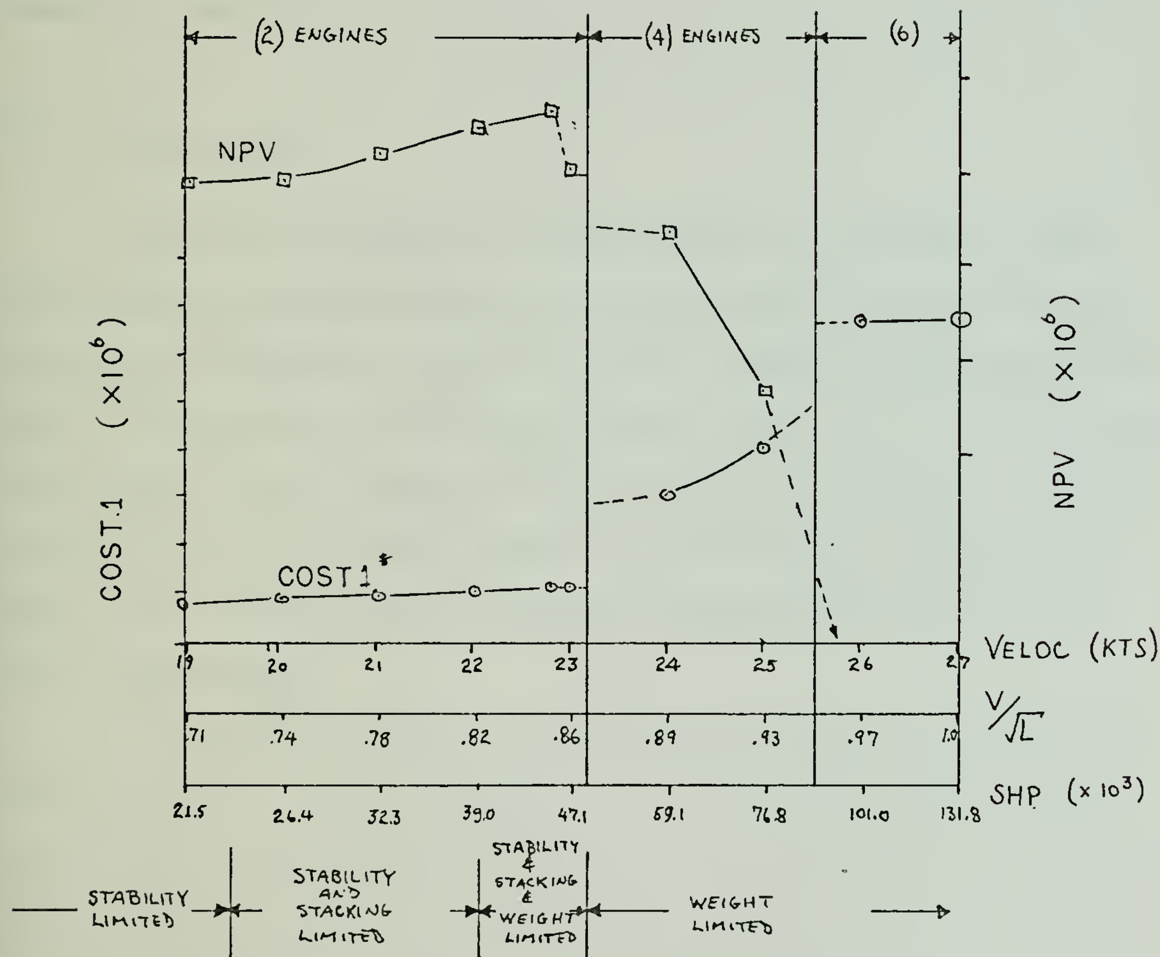
* COST OF BALLAST WT. REMOVED.

Figure 17

OBJECTIVE SURFACE PROFILE
FOR DESIGN ALTERNATIVE THREE

SHIP GEOMETRY	
Δ	39,641. TONS
L	723.′
B	94.1′
T	32.2′
D	58.7′
CP	.69
2 SHAFTS	

FR = $200./TON



* COST OF BALLAST WT. REMOVED.

Figure 18

and this resulted in a loss of about fifty containers. As stated earlier, the length of the engine box was modeled solely as a function of the required shaft horsepower. If the engine box were modeled more accurately, the loss of cargo may have occured at the same time that additional engines were added. The graph of Alternative Number 3 shows a similar drop in the value of the objective function. This is again associated with the engine box size. At the bottom of each graph, the tight constraints are listed for the various design speeds.

9.7 Sensitivity

The final segment of the analysis is concerned with determining the sensitivity of the design solutions and the associated objective values. Only a limited effort was possible in this area, but this section should help to re-enforce confidence in the results of the previous sections. The results of this step will point out the critical assumptions made in the design model and where additional effort may prove rewarding.

In order to obtain a sensitivity analysis in a general search routine, it is required that perturbations be made in the values of the decision variables and the input parameters. Here we will study the sensitivity of the design Alternative 4 due to variations in discount factor, propulsion coefficient,

midships coefficient, endurance,freight rate and the number of extra engines that may be required for increased reliability.

The procedure was to start with the best alternative available, and determine the affect of changing one factor at a time. The changes on the worth of Alternative 4 are noted for each perturbation. In Column B of the table, the NPV objective resulting from the change is recorded. This design was used as a starting point for the SUMT Program. Column C indicates the worth of the design resulting from the optimization. A qualitative indication of the overall changes are also given.

The most critical factor in the design was the assumed value of the discount factor. A variation in this input parameter caused the greatest change in the design. There are several other elements that deserve explanation. The sensitivity of the design to the assumption of P.C. may be more important than indicated by a quick look at the figures. The reduction in the P.C. resulted in a design with a higher block coefficient. This would cause an even further decrease in the P.C. for the design. The other interesting effects are noted on the table. The design incorporates a severe cost on the design for ballast. When the ballast is replaced by fuel, there is a sufficient increase in the NPV of the design. This appears twice in the analysis.

Table 13

SENSITIVITY ANALYSIS

PARAMETER P	INITIAL VALUE OF $P=P_1$	FINAL VALUE OF $P=P_2$	ΔP	OBJECTIVE VALUE			B−C	$\frac{B-C}{\Delta P}$	EFFECT ON DESIGN REFERENCED FROM ALTERNATIVE 4
				A SOLUTION w/ P_1	B SOLUTION 'A' w/ P_2	C OPTIMAL SOLUTION w/ P_2			
DF	.20	.15	−.05	47.2	62.6	67.3	−4.7	94.	LARGER SHIP
DF	.15	.10	−.05	67.3	89.1	98.3	−9.2	184.	SMALLER SLOWER SHIP
PC	.65	.625	−.025	47.2	43.1	43.6	−.5	20.	SLIGHTLY HIGHER BLOCK COEF.[1]
CM[2]	.925	.950	+.025	47.2	47.2	49.2[3]	−2.0	−80.	SLIGHTLY LARGER SHIP
NO. ENGINES	2	4[4]	+2	47.2	46.33	46.37	−.04	−.02	SLIGHTLY LONGER SHIP
ENDURANCE	12,500	15,000	+2,500	47.2	45.0	49.5[5]	−4.5	—	SLIGHTLY LOWER CP
FR	100.	90.	−10	47.2	38.9	39.0	−.1	.01	SLIGHTLY SMALLER Δ

1. Change which could cause a further decrease in PC
2. Effect on powering not assessed
3. Ballast replaced by fuel
4. Two engines as on line spares
5. Ballast replaced by fuel

CHAPTER X

CONCLUSIONS AND RECOMMENDATIONS

10.1 General

As the first iteration of the design procedure is culminated for the sample problem, it is important to put the discussion in context with the overall design philosophy. The preliminary design was pursued in this problem with a broader interpretation of the owner's requirements as was made possible by the quantification of the owner's preferences. It was found that this approach resulted in a streamlining of the design step which permitted a larger range of alternatives to be evaluated. The results from the sample problem would be presented. In the proposed design process in Figure 4, the next step would involve an evaluation of results of each system design by the owner. This would be followed by a possible decision to iterate in the design of the ship with modified criteria.

The ourput of the design step should provide useful information of the owner so that future iterations will converge faster to the design selected. There will be many occasions where the owner will want to have results of a design based on the traditional requirements of speed and payload capacity. This approach used should prove adaptable. The information on sensitivity would be obtained.

10.2 Optimization in the Design Process

We have seen that the computational efficiency of the computer has permitted extensive parametric study of the ship design. The interaction between the problem formulation and the solution technique has been demonstrated. The application of the Sequential Unconstrained Minimization Technique resulted in a straightforward design sequence that could be used to evaluate many design alternatives. The ship design model was developed to provide the information necessary to identify the objective surface for an optimization procedure. In the sample problem, the surface was generated using the net present value for measuring the cash flows expected over the ship's lifetime.

The thesis has shown that partial optimization of a ship design is possible if the problem can be structured. It was also observed that interaction of the designer with the program is needed to achieve the maximum benefit from the programs.

10.3 Experience with SUMT

The experience with the SUMT program generated several observations releveant to the design process. The first is that a programmed search which requires derivatives of the surface, could be employed using linear interpolation of the

derivatives and remain relatively efficient. The SUMT Program used such a linear interpolation scheme to determine the partial derivatives of the objective surface. This efficiency was improved by deriving the design constraints so that interpolation of their derivatives would not be necessary. For those constraints which were not expressed in closed form, they were handled internal to the design model by insuring that the ship designs would satisfy these constraints. The non-linear stability constraint was handled this way because the change in stability could not be determined from the decision variables along, but must include the effect of the container loading. The design model was constructed to insure that all alternatives would meet the stability constraint by controling the loading of containers.

A second observation dealing with data restrictions should be imposed external to the design model. When they were introduced internally, it was difficult to assign appropriate penalties within the design model to keep the design feasible. No matter what reasonable level of penalty was assigned, the program would find alternatives that did not satisfy these constraints.

The imposition of the equality constraints was not found to be practical in this design application because none of the intermediate designs were feasible. It was only after the parameter "r" was sufficiently small that the

equality constraints imposed sufficient penalty to the modified objective function. It was preferred that the equality be replaced by only a single one way constraint. If two inequalities were imposed, the associated penalty in the objective function would be of infinite value and as such would obscure the real driving factors in the problem. This approach was used for the equality constraint of the block coefficient in the sample problem. The nature of the problem caused the program to design ship alternatives with as large a block coefficient as possible. The equality was replaced by an upper bound.

There are two other observations on the application of the program which should benefit future users. The first deals with starting points for the program and the second with the selection of the value of the parameter "r". With the regard to the first, in the present form of the SUMT Program, it is recommended to start the search with a feasible design. The program is capable of finding its own feasible starting solution, however, the barrier penalty technique used in the optimization program requires a separate method for finding a feasible starting solution and attempts to employ its use has resulted in unreasonable alternatives. A feasible starting solution would prevent the excessive costs experienced when this feature was tried.

Finally, it is recommended that the selected value for "r" and for the associated reduction ratio which determines

the successive values of "r" be determined as follows. Looking first at the modified objective function, it is important to have the values of the constraint and objective functions of the same magnitude during the first iteration. This will insure that the program encounters both the affects of the objective surface and the constraint penalties in the initial phases of its search. If the value of the constraint were larger than that of the objective function, the first several iterations would produce solutions that did not observe the contour of the objective surface. If on the other hand, the objective value were larger, the program may satisfy the given convergence criteria prior to reaching a local optimum on the surface.

In the sample problem this sizing was accomplished in two ways. First, the objective value was expressed in millions of dollars. This resulted in the objective value being of the same order of magnitude as most of the penalty values that were possible from the constraints. For this reason, the value of "r" was set equal to one. Other combinations have worked as well. The selected value of the reduction ratio depends on the convergence of the sequence of subprogram solutions. Most of the improvements in the sample problem optimizations were made in the first few iterations. The remaining iterations were to decrease the

penalty values so that the convergence criteria would be satisfied. I would recommend using a higher ratio than twenty which was used in the sample problem.

10.4 Areas for Additional Study

Future applications of the design program could provide even more realistic results if the following improvements were incorporated. They were not included in this program due to the limited resources available. The following comments cover most of the areas that could use additional effort.

Propulsive Coefficient

The sensitivity analysis showed that the solution is sensitive to variations in the propulsive coefficient. As the design alternatives develop blunt sterns, the efficiency of the propulsor will decrease. The ship propeller interaction should be included. The determination of the actual propeller would also prove helpful. One approach to determining propeller fit is covered in Reference 45.

Other Constraints

Additional constraints commonly handled, such as the requirements on the period of roll should be included. This would require only a slight change in the program. Also the volume requirements were used only to determine feasible container configurations. The addition to the model of

restrictions due to fuel and ballast volumes should be developed internal to the model. The volume requirements of the engineering space should be more carefully defined, especially since the length of this compartment is used to calculate the length available for containers.

Velocity in a Seaway

The additional resistance experienced in the seaway causes a loss of speed. The program uses a simplified model to predict this loss. A subprogram would prove useful in determining the value more accurately.

Interaction with Terminal

The program presently uses a very simplified interaction measure. The model could be expanded for a specific situation to determine the actual turnaround times and charges. This would require information on the container handling capabilities, both in terms of speed of operation but also the inventory capacity.

Backhaul

Any actual study should investigate backhaul opportunities and incorporate their effects.

Maintenance

Maintenance was assumed to impose an annual dollar cost. If an overhaul policy is known, the cash flows should be adjusted. The Net Present Value objective function is the only measure which could handle the non-uniform cash flow.

Seakeeping

An effort should be made to determine the seakeeping qualities of the design. At the least, limits of performance could be included in the constraints. One such limit would be the deck wetness criteria of Reference 39.

Powering Prediction

This program used the Taylor Standard Series to predict ship resistance. Other predictors such as the Series 60 could be easily employed. Of primary concern is the powering predictions for designs with large block coefficients. Another alteration would provide calculation of resistance for the different ballast conditions.

10.5 Applications

The design model was developed for the preliminary design of a containership. There are other ship types which could be studies with the existing program. For example, a LASH or Barge Ship could be considered, also bulk carriers or oil carriers could be designed. This would require an adjustment in the input parameters describing the size and weights of the containers. The barge is a large container and the analogy is obvious. The bulk carrier on the other hand is loaded in a continuous way. By loading small blocks of oil, the program could approximate the cargo

carried.

Another application of the program would call for its use to test the effects of governmental policies on the nation's merchant fleet composition. The effect of subsidies has the effect of changing the economic preferences of ship owner's for different ships. The model could show the trends in the fleet population that were due to these policies and regulations. Of more immediate concern is the effect of oil prices on the design.

The last suggested application involves using the programs as a teaching aid in a graduate course in ship design. The following characteristics make this application attractive. First, the student is required to provide a feasible starting point for the design. This could be the result of a hand calculation and as such provides an opportunity to understand the design methods. Secondly, the design program could then be used to generate the data to check the student's design accuracy for his selection of decision variables. Finally, the optimization program would provide other design alternatives so that the student could be exposed to a higher level in the design process. As such, this would provide an interactive tool to permit a more complete design effort in the more advanced design courses.

FOOTNOTES

1.	Ref. 16	p. 1-5
2.	Ref. 11	
3.	Ref. 20	
4.	Ref. 38	p. 34
5.	Ref. 22	p. 17
6.	Ref. 29	
7.	Ref. 35	
8.	Ref. 5	p. 46-50
9.	Ref. 8	p. 7
10.	Ref. 37	
11.	Ref. 42	p. 3
12.	Ref. 42	
13.	Ref. 52	p. 55
14.	Ref. 52	p. 219

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XIII. APPENDICES

Appendix A

VARIABLE DEFINITIONS

Table 14

DEFINITION OF TERMS

ADMIN	=	ANNUAL ADMIN AND MISC OPERATING COSTS
AIC	=	ANNUAL INSURANCE COST
AIR	=	ANNUAL INSURANCE RATE
ALPHA	=	WATERPLANE INERTIA COEFFICIENT
ANENG	=	NUMBER OF TURBINES INSTALED IN THE SHIP
ANPV	=	NET PRESENT VALUE
AOC	=	ANNUAL OPERATING COSTS
APC	=	ANNUAL PORT COST
APW	=	AVAILABLE PAYLOAD WEIGHT
AVAIL	=	SHIP AVAILABILITY
AVRM	=	AVAILABLE WEIGHTED MOMENT FOR PAYLOAD AND BALAST
BDR	=	BEAM-DRAFT RATIO
BE	=	EFFECTIVE BEAM OF THE SPACE ON THE SHIP FOR CONTAINERS
BEAM	=	SHIP BEAM
BEAMM	=	MAXIMUM BEAM
BM	=	METACENTRIC HEIGHT ABOVE THE CENTER OF BUOYANCY
CASHI	=	INITIAL COST TO OWNER
CB	=	SHIP BLOCK COEFFICIENT
CC	=	ANNUAL CREW COSTS
CM	=	SHIP MIDSHIP SECTION COEFFICIENT
COST1	=	INITIAL BUILDING COST OF THE SHIP
COST3	=	COST OF BALAST
COST4	=	COST OF MACHINERY
CO	=	COST OF OUTFIT
CP	=	SHIP PRISMATIC COEFFICIENT
CR(6210)	=	RESIDUAL RESISTANCE COEF. FOR TSS POWERING CALCULATION
CS	=	COST OF STEEL
CTR	=	CORPORATE TAX RATE
CV	=	SHIP VOLUMETRIC COEFFICIENT
CWP	=	SHIP WATERPLANE COEFFICIENT
DBP	=	DISTANCE BETWEEN PORTS
DCF	=	STANDARD CORRECTION FACTOR FOR RESISTANCE COEFFICIENT
DE	=	EFFECTIVE DEPTH OF SPACE ON THE SHIP FOR CONTAINERS
DEPTH	=	SHIP DEPTH
DF	=	DISCOUNT FACTOR FOR ANPV CALCULATION
DISPL	=	SHIP DISPLACEMENT
DOUBLE	=	HEIGHT OF DOUBLE BOTTOM
DPF	=	DAILY PORT FEES
DRAFT	=	SHIP DRAFT
DRAFTM	=	MAXIMUM DRAFT
E	=	ENDURANCE DISTANCE
EDEPTH	=	EFFECTIVE DEPTH OF A CONTAINER
ELENGT	=	EFFECTIVE LENGTH OF A CONTAINER
EWIDTH	=	EFFECTIVE WIDTH OF A CONTAINER
FC	=	FUEL CONSUMPTION
FINAN	=	FINANCED
FR	=	FREIGHT RATE CHARGED FOR TRANSPORT DOLLARS PER TON
GAMMA	=	SPECIFIC GRAVITY OF SEA WATER
GMREQ	=	REQUIRED METACENTRIC HEIGHT
AITC	=	INVESTMENT TAX CREDIT

GNJ	=	CONVERSION FACTOR FROM KTS TO FPS
KB	=	CENTER OF BUOYANCY
KGB	=	CENTER OF GRAVITY OF BALAST WEIGHT
KGM	=	CENTER OF GRAVITY OF MACHINERY WEIGHT
KGO	=	CENTER OF GRAVITY OF OUTFIT WEIGHT
KGS	=	CENTER OF GRAVITY OF STEEL WEIGHT
KGX	=	CENTER OF GRAVITY OF MISC WEIGHT
LBR	=	LENGTH-BEAM RATIO
LDR	=	LENGTH-DEPTH RATIO
LF	=	EFFECTIVE LENGTH OF THE SPACE ON THE SHIP FOR CONTAINERS
LENGT	=	SHIP LENGTH
LENGTM	=	MAXIMUM LENGTH
LM	=	LENGTH OF SHIP TAKEN UP BY MACHINERY SPACES
LP	=	LENGTH OF SHIP TAKEN UP BY PEAK TANKS
MD	=	MAXIMUM NUMBER OF EXTERIOR DECKS OF CONTAINERS
MRC	=	ANNUAL MAINT AND REPAIR COSTS
NBE	=	NUMBER OF CONTAINERS ACROSS
ND	=	MAXIMUM NUMBER OF INTERIOR DECKS FOR CONTAINERS
NDE	=	NUMBER OF CONTAINERS DEEP
NENG	=	NUMBER OF TURBINES INSTALED IN THE SHIP
NLE	=	NUMBER OF CONTAINERS LONGITUDINALLY
NN	=	PERIOD OF INTEREST FOR LOAN AND LIFE OF SHIP
PC	=	PROPULSIVE COEFFICIENT
PCF	=	PORT CALL FEES PER ROUND TRIP
PF	=	PERCENT FINANCED
PRICE	=	PRICE OF FUEL IN DOLLARS PER TON
R	=	ANNUAL REVENUES
RATE	=	INTEREST RATE ON LOAN
RMMAX	=	MAXIMUM RIGHTING MOMENT AVAILABLE FOR PAYLOAD AND BALAST
SFC	=	SPECIFIC FUEL CONSUMPTION
SHP	=	SHAFT HORSE POWER
SHPM	=	MAXIMUM CONTINUOUS SHP OF A SINGLE GAS TURBINE
SHPMAX	=	MAXIMUM SHP AVAILABLE FROM PROPULSION PLANT
SHPREQ	=	REQUIRED SHP TO DRIVE SHIP AT VELOCITY VELOC
SS	=	ANNUAL SUPPLY AND STOCK COSTS
SUBSID	=	SUBSIDY
SUBSR	=	SUBSIDY RATE
SV	=	SALVAGE VALUE
TD	=	AVERAGE INPORT DELAY TIME IN DAYS
TPY	=	ROUND TRIPS PER YEAR
VELOC	=	SHIP VELOCITY
VELOCE	=	ENDURANCE VELOCITY
VELOCS	=	SHIP SPEED MADE GOOD IN SEAWAY
VLR	=	VELOCITY-SQUARE ROOT OF LENGTH RATIO
VOL	=	SHIP DISPLACED VOLUME
WB	=	BALAST WEIGHT
WC	=	AVERAGE WEIGHT OF A CONTAINER IN TONS
WF	=	FUEL WEIGHT
WINGT	=	WING TANK SIZE (INCLUDES BOTH TANKS)
WM	=	WEIGHT OF MACHINERY

```
WO      = WEIGHT OF OUTFIT
WP      = PAYLOAD WEIGHT
WPKG    = RIGHTING MOMENT OF PAYLOAD
WPMAX   = MAXIMUM WEIGHT AVAILABLE FOR PAYLOAD AND BALLAST
WS      = WEIGHT OF STEEL
WW      = MAXIMUM WEIGHT OF PAYLOAD PERMITTED
WX      = MISC WEIGHT
YFC     = ANNUAL FUEL COST
```

Appendix B

EQUATION DEFINITION

Contents

Empirical and Other Equations Used for Cargo Ship Model

The equations presented in this appendix are taken from reference [1] and form the basis for the computations that are carried out in step 3 of each sampling cycle. These equations could undoubtedly be presented in different form with improved accuracy. The equations are listed in seven major groups: (1) Weights, W, (2) Volumes, V, (3) Freeboard, F, (4) Stability, S, (5) Cost, C, (6) Power, P, and (7) Miscellaneous, M.

1 *Weights* (all weights are given in long tons).

(*a*) Approximation to outfit weight

$$W_o = 0.15\left[\frac{(L \times B)\,K_o}{100}\right]^{1.00} \qquad (1W)$$

$$K_o = 0.080$$

(*b*) Approximation to steel weight

$$W_s = 2.107\left[\frac{L(B + D) \times K_s}{100}\right]^{1.10} \qquad (2W)$$

(*c*) . Approximation to wet machinery weight

$$W_m = 7.18\ \mathrm{SHP}^{0.493} \qquad (3W)$$

(*d*) Weight of fuel oil required to sail the specified distance, E plus 10 percent allowance, at a given speed, (V).

$$W_f = \frac{(1.10E) \times \mathrm{SHP} \times \mathrm{FR}}{2240 \times V} = 0.491 \times 10^{-3} \times \left[\frac{E \times \mathrm{SHP} \times \mathrm{FR}}{V}\right] \qquad (4W)$$

(*e*) Approximate fuel rate

$$\mathrm{FR} = 0.5\ \mathrm{SHP}/(\mathrm{SHP} - 855) \qquad (5W)$$

(*f*) Miscellaneous deadweight

$$W_e = 300 \qquad (6W)$$

(*g*) Actual payload weight

$$W_p = \Delta - W_o - W_s - W_m - W_f - W_e \qquad (7W)$$

where $\Delta = x_1$ (see Table 1).

2 *Volumes* (all volumes given in cubic feet).

(*a*) Approximate gross bale cubic of the ship. This value applies to all dry-cargo ships except where excessive sheer is used. This expression includes machinery space volume and excludes the double-bottom, settler, and peak tanks

$$\mathrm{GBC} = 0.875[L \times B \times D \times C_B]K_v \qquad (1V)$$

(*b*) Approximate fuel-oil capacity in the double bottom. This equation is used in conjunction with equation (3V) to determine whether adequate volume exists to accommodate the fuel oil computed by equation (4W).

$$(\mathrm{Vol})_{fo} = [(K_v \times L) \times B \times (K_d \times D) \times (0.69\,C_B)] = 0.788\,K_d \times \mathrm{GBC} \qquad (2V)$$

where

$K_d \approx 0.11$

C_B = block coefficient at LWL; factor 69 percent is a correction for (*a*) structure in inner bottom, and (*b*) correction to obtain C_B at the WL height equal to tank top height. Fuel-oil stowage factor is 37.2 cu ft/ton

(*c*) Approximate fuel-oil settler-tank capacity

$$(\mathrm{Vol})_{ft} = 5600\ \text{cu ft}\quad (150\ \text{tons}) \qquad (3V)$$

(*d*) Approximate machinery space volume

$$(\mathrm{Vol})_m = 47{,}632 + 7.112\,(\mathrm{SHP}) \qquad (4V)$$

(*e*) The actual payload volume is

$$\mathrm{Vol}_p = \mathrm{GBC} - \mathrm{Vol}_{machinery} - [37.2\,W_f - (\mathrm{Vol}_{fo} + \mathrm{Vol}_{ft})] \qquad (5V)$$

(*f*) The stowage factor is

$$\mathrm{SF} = \mathrm{Vol}_p/W_p \qquad (6V)$$

3 *Freeboard* (all freeboard dimensions are in inches).

(*a*) Available freeboard. Equation assumes 3-in. margin line and that the uppermost continuous deck is the freeboard deck. Equation will differ for a shelter-deck ship

$$F_a = 12\,[D - (0.25 + T)] \qquad (1F)$$

(*b*) Minimum permissible freeboard from USCG Load Line Regulations.

For: $L \leqq 400$ ft:

$$F_r \geqq 4.21 + 3.59\,\frac{(L)}{100} + 3.71\left(\frac{L}{100}\right)^2 \qquad (2F)$$

For: $400\ \text{ft} \leqq L \leqq 750$ ft

$$F_r \geqq -77.67 + 42.58\,\frac{L}{100} - 0.60\left(\frac{L}{100}\right)^2 - 0.08\left(\frac{L}{100}\right)^3 \qquad (3F)$$

For $L \geq 750$ ft.

$F_r \geq .2322 \times L$

4 *Stability*

(*a*) Approximation to the transverse inertia coefficient of the design load water plane, α = trans. waterplane inertia/LB^3

$$\alpha = 0.0657\ C_p - 0.0122 \qquad (1S)$$

(*b*) Approximation to the KG of steel

$$KG_s = K_3\ D$$
$$K_3 \approx 0.61 \qquad (2S)$$

(c) Approximation to the KG of outfit

$$KG_o = K_4\ D$$
$$K_4 \approx 1.00 \qquad (3S)$$

(*d*) Approximation to the KG of payload

$$KG_p = K_7\ D$$
$$K_7 \approx 0.63 \qquad (4S)$$

(*e*) Approximation to the KG of miscellaneous deadweight

$$KG_z = K_8\ D$$
$$K_8 \approx 1.00 \qquad (5S)$$

(*f*) Approximation to KG of fuel oil in settler tanks

$$KG_{fs} = K_6 D + 4.80$$
$$K_6 = 0.11 \qquad (6S)$$

(*g*) Approximation to KG of fuel oil in double bottom. For normal ships this is taken as (2/3) (tank top height)

$$KG_{fb} = 0.67\ K_6 D \qquad (7S)$$

(*h*) Approximation to machinery KG, with boilers full and for conventional arrangement for steam-turbine plant

$$KG_m = 0.55\ D \qquad (8S)$$

(*i*) The available GM in the full-load condition uncorrected for free surface is approximated by

$$GM_a = K_2 T + \frac{LB^3\alpha}{35 \times \Delta}$$
$$- [(W_s KG_s + W_o KG_o + W_m KG_m$$
$$+ (W_f - W_{fs}) KG_{fb} \qquad (9S)$$
$$+ W_{fs} KG_{fs} + W_z KG_z + W_p KG_p]/\Delta$$
$$K_2 \approx 0.54$$

(*j*) The required GM is

$$GM_r \geq 0.05\ B \qquad (10S)$$

(This required GM is also for the full-load condition, uncorrected for free surface.)

5 *Costs* (all costs are given in terms of cost points which are related to dollars by a factor of between 1 and 50.)[18]

(*a*) Outfit costs

For: $0 \leq W_o \leq 1400$ tons

$$C_o = [1100 - 0.043\ W_o + (0.142 \times 10^{-3}) W_o^2 - (0.1323 \times 10^{-6}) W_o^3]\ W_o \qquad (1C)$$

For: $1400 < W_o < 2600$ tons

$$C_o = [2430 - 1.928\ W_o + (0.722 \times 10^{-3})\ W_o^2 - (0.091 \times 10^{-6})\ W_o^3]\ W_o \qquad (2C)$$

For: $W_o \geq 2600$ tons

$$C_o = 698.8\ W_o \qquad (3C)$$

(*b*) Approximation to steel cost

$$C_s = \left[218.4 - 21.38\left(\frac{W_s}{1000}\right) + 2.061\left(\frac{W_s}{1000}\right)^2 - 0.1149\left(\frac{W_s}{1000}\right)^3\right] W_s \qquad (4C)$$

(*c*) Approximation to machinery cost. (SHP is normal shaft horsepower.)

For: SHP $\leq$ 13,000

$$C_m = \left[137.7 - \frac{\text{SHP}}{75.32 + \frac{(\text{SHP})}{1000}(5.92)}\right] \text{SHP} \qquad (5C)$$

For: SHP $\geq$ 13,000

$$C_m = \left[\frac{\text{SHP}}{3.249\ (\text{SHP}) - \frac{173.95}{100}}\right] \text{SHP} \qquad (6C)$$

(*d*) Annual fuel cost

$$C_f = K_{10} K_5 W_f V/E$$
$$K_{10} \approx 5265 \text{ for this study} \qquad (7C)$$
$$K_5 = 3.09 \text{ cost pts./ton}$$

An explanation of K_{10} is given in section 8 of this Appendix.

(*e*) Total annual cost. Cost

The yearly fuel cost [equation (7C)] is included in this cost which is computed as follows:

$$\text{Cost} = 0.0656 \times (C_o + C_s + C_m) + C_f \qquad (8C)$$

where the fraction 0.0656 reduces the total initial building cost to a yearly cost using the assumptions:

[18] The term cost points is used in [1] to avoid direct association with dollars.

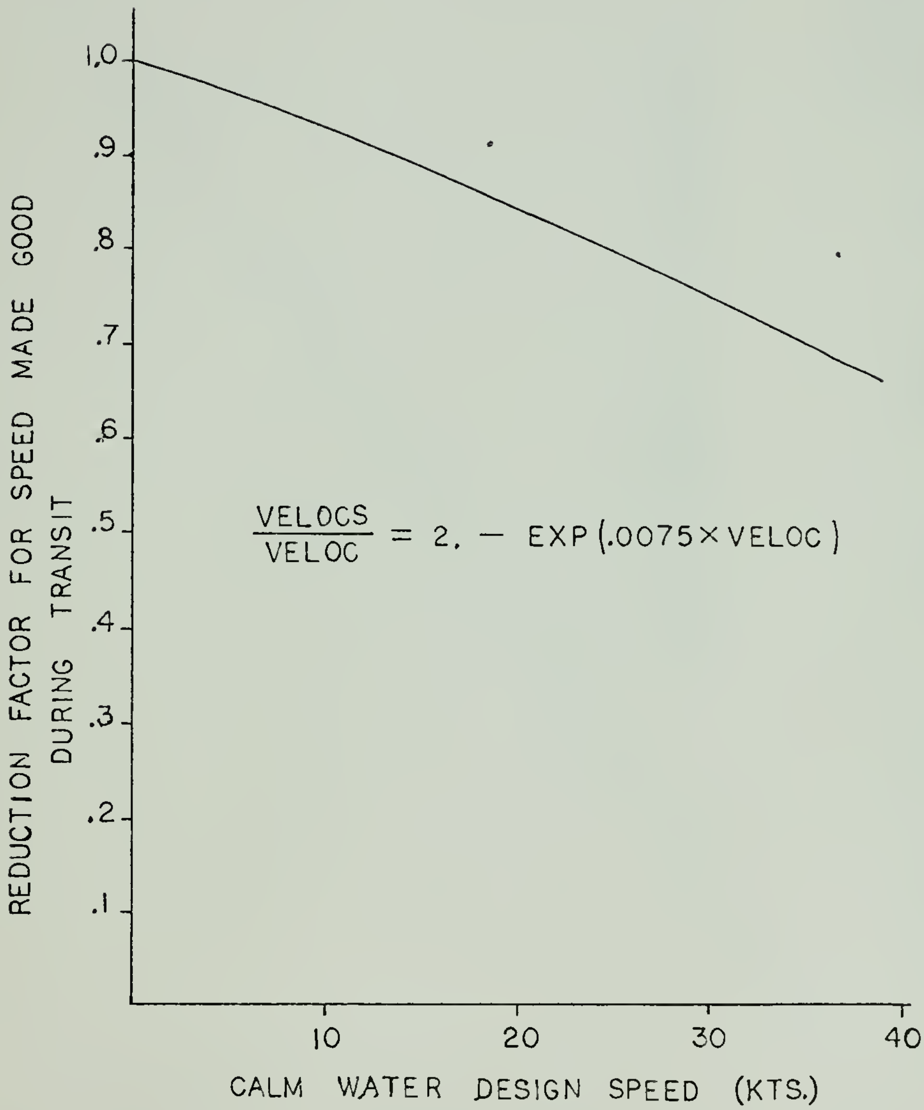
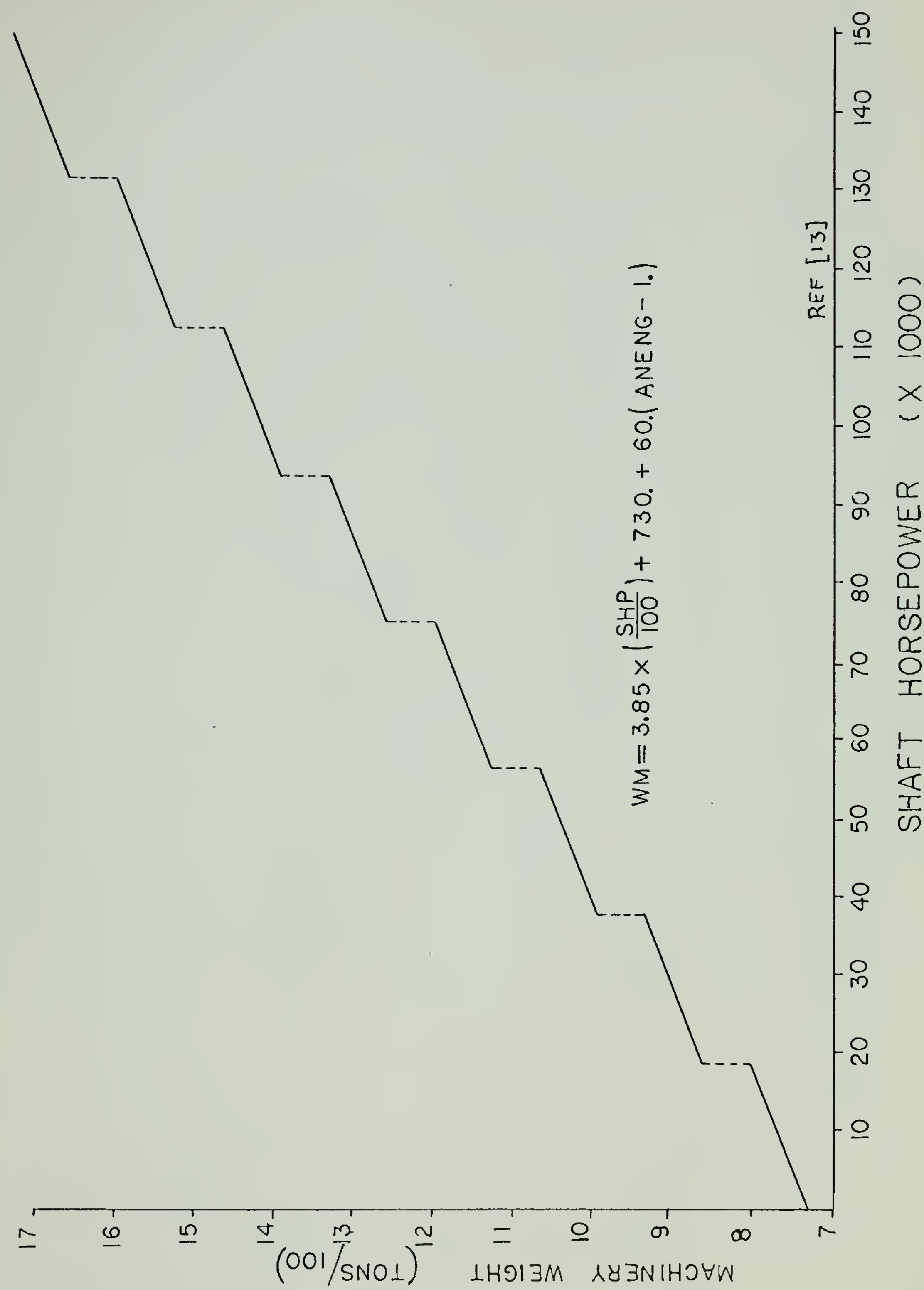
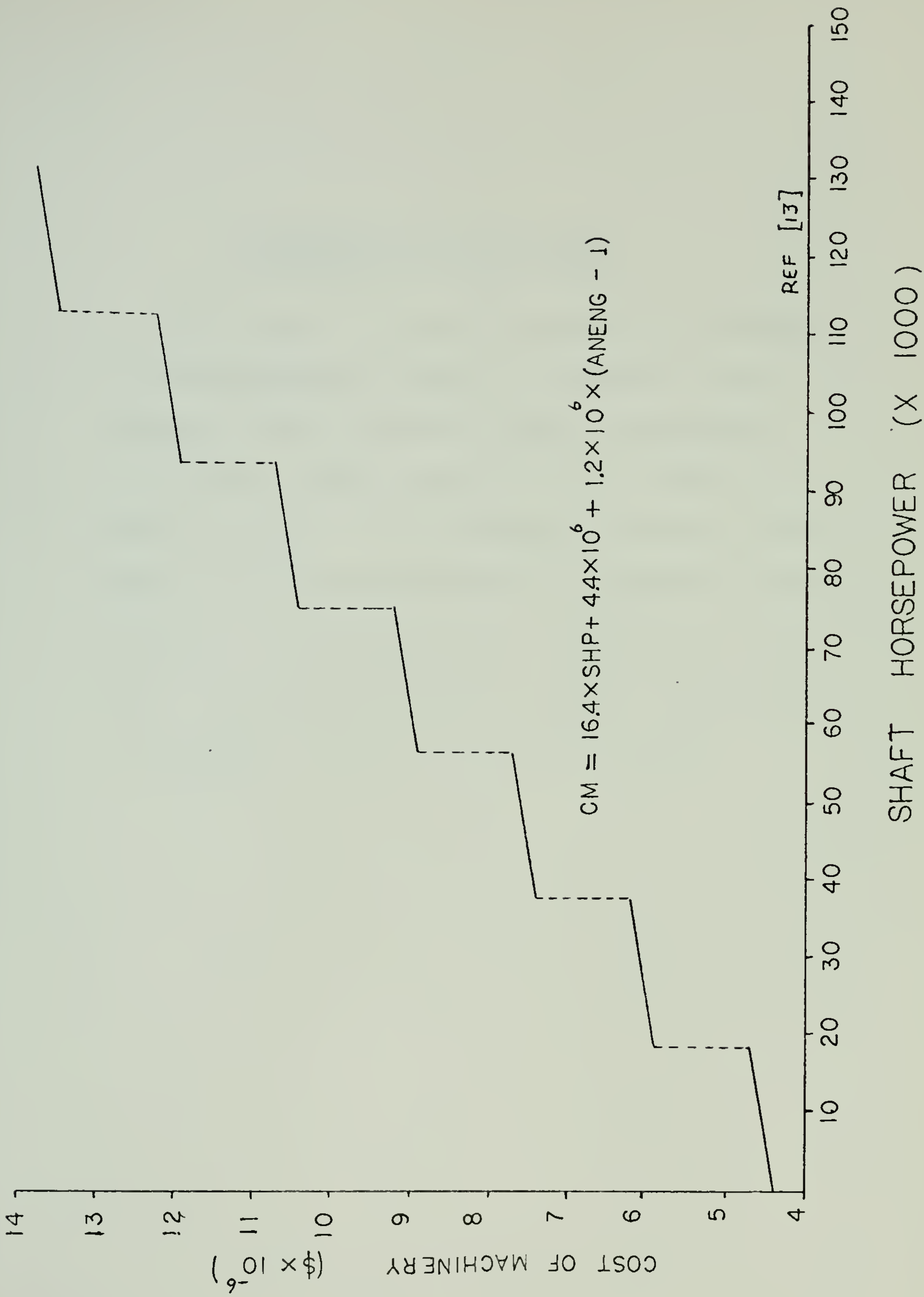

1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
10
20
30
40
REDUCTION FACTOR FOR SPEED MADE GOOD DURING TRANSIT
CALM WATER DESIGN SPEED (KTS.)
VELOCS / VELOC = 2. − EXP(.0075 × VELOC)

Figure 19



WM = 3.85 × (SHP/100) + 730. + 60.(ANENG - 1.)
REF [13]
SHAFT HORSEPOWER (X 1000)
MACHINERY WEIGHT (TONS/100)
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
7 8 9 10 11 12 13 14 15 16 17

Figure 20



CM = 16.4×SHP+ 4.4×10^6 + 1.2×10^6 × (ANENG − 1)
REF [13]
SHAFT HORSEPOWER (X 1000)
COST OF MACHINERY ($× 10^-6)

Figure 21

EXPLANATION OF SFC MODEL

The graph in Figure 22 shows the minimum SFC as engines are added to the power plant to achieve a given installed shaft horsepower. The initial segment shows the SFC curve for a single engine. For the multiple engine installations, the same minimum SFC is achieved at installed shaft horsepowers of multiples of 18,700 SHP. For the intermediate powers, all engines are assumed to operate at equal levels.

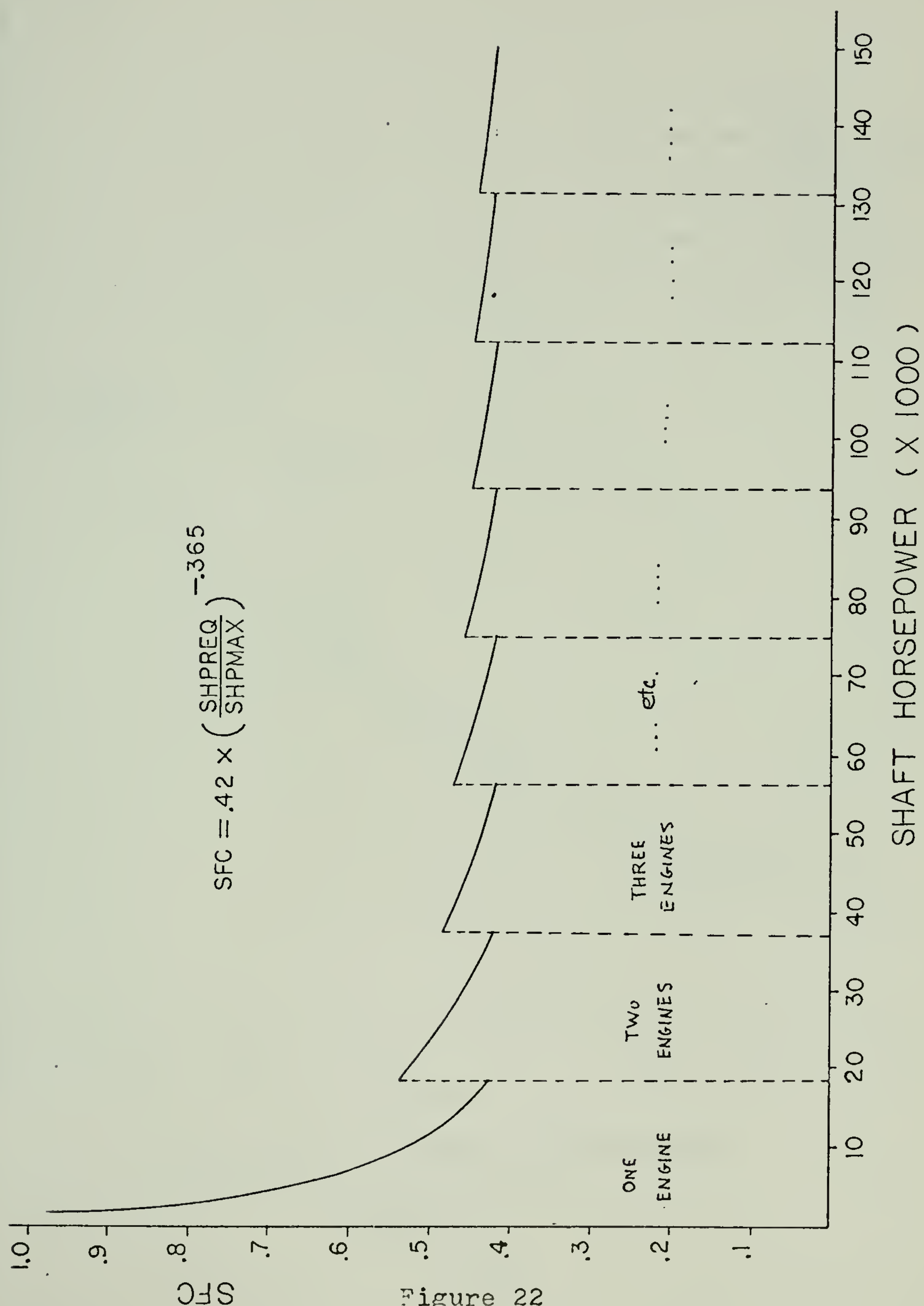
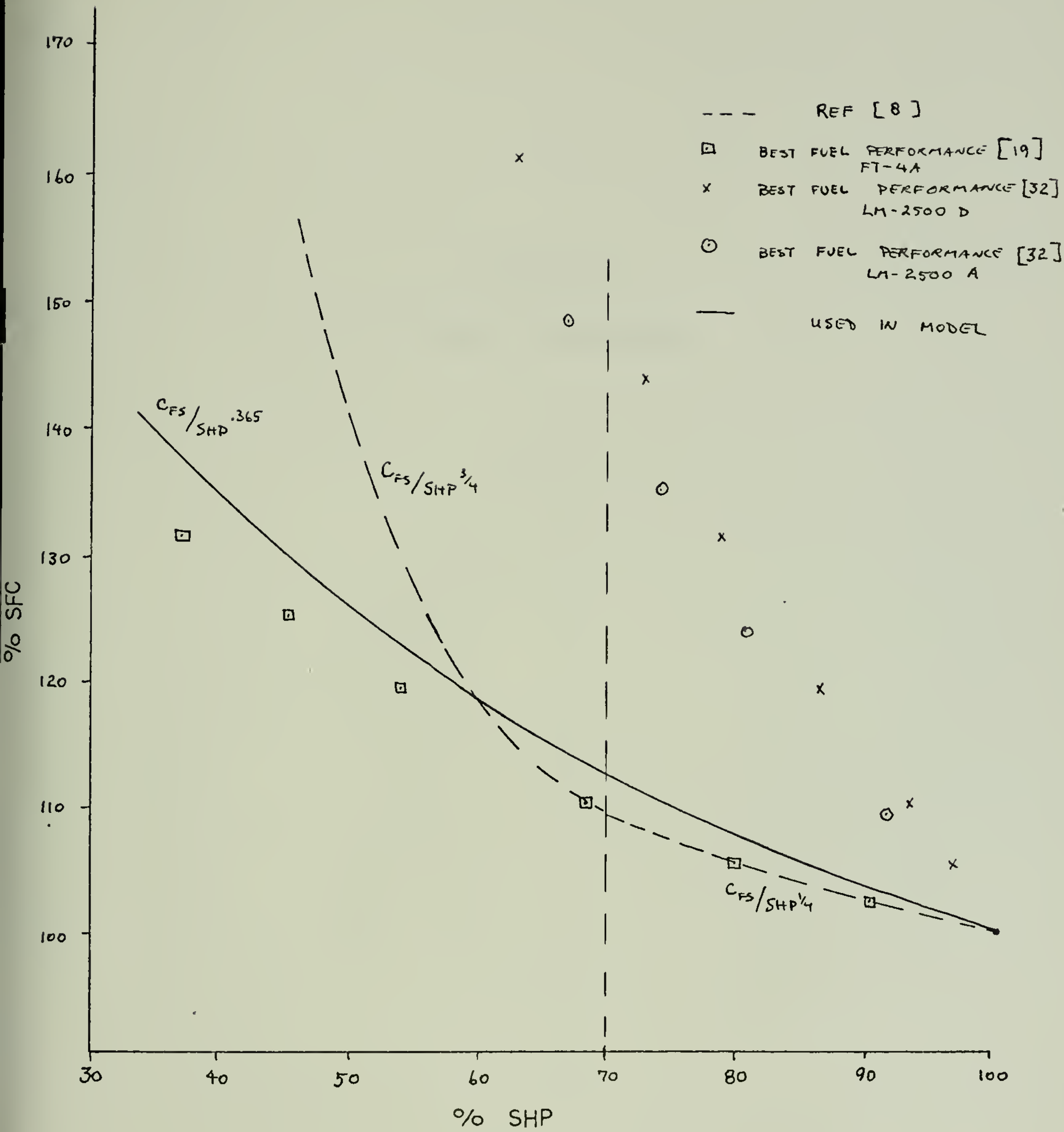

SFC
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
SFC = .42 × (SHPREQ / SHPMAX)^-.365
ONE ENGINE
TWO ENGINES
THREE ENGINES
... etc.
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
SHAFT HORSEPOWER (X 1000)

Figure 22



SFC CURVES FOR MARINE GAS TURBINES

Figure 23

Appendix C

INPUT PARAMETERS

N.N.S. DESIGN

PROGRAM INPUT PARAMETERS

PARAMETER	SYMBOL	VALUE
DESIGN PARAMETERS		
PROPULSIVE COEFFICIENT	PC	.75 (APPENDAGE 1.03)
ENDURANCE	E	12,500.
DISTANCE BETWEEN PORTS	DBP	5000
SHIP AVAILABILITY	AVAIL	.98
NUMBER OF SHAFTS	NSHAFT	1
MIN. NO. OF ENGINES*	NENGU	(−)
NO. OF SPARE ENGINES	NEXTRA	0
MAX. PAYLOAD WT.	WW	20,000
MIN. PAYLOAD WT.	WPMIN	0
MAX. CONTAINER STACKING	ND	7
MAX. STACKING ABOVE DK.	MD	2
AVERAGE CONTAINER WT.	WC	11.86
EFFECTIVE CONT. LENGTH	ELENGT	23.0
EFFECTIVE CONT. WIDTH	EWIDTH	8.75
EFFECTIVE CONT. DEPTH	EDEPTH	8.02
DOUBLE BOTTOM THICKNESS	DOUBLE	2.5
BALLAST WEIGHT KG.	KGB	2.0
MAX. SHP FOR SINGLE ENG.	SHPM	N.A.
SEA SPEED FACTOR	BETA1	.0075
SFC FACTOR	BETA2	.365
MISC. WEIGHT	WXX	0
MISC. WEIGHT KG.	XKGX	0
DESIGN WEIGHTING FACTORS		
FACTOR FOR OUTFIT WT.	WWO	1.
FACTOR FOR STEEL WT.	WWS	1.
FACTOR FOR MACHINERY WT.	WWM	1.

* NEGATIVE VALUE INDICATES STEAM TURBINE PROPULSION.

Table 15

N.N.S. (CONT)

PROGRAM INPUT PARAMETERS

PARAMETER.	SYMBOL	VALUE
NAVIGATION CONSTRAINTS		
MAX. LENGTH	LENGTM	900
MAX. BEAM	BEAMM	110
MAX. DRAFT	DRAFTM	37
ECONOMIC PARAMETERS		
FREIGHT RATE	FR	50.
PORT CALL FEE	PCF	1000.
DAILY PORT FEE	DPF	1000.
PRICE OF FUEL	PRICE	16.5
ANNUAL INSURANCE RATE	AIR	.1
ASSET LIFE	NN	25.
SALVAGE VALUE	SV	0
DISCOUNT FACTOR	DF	.20
SUBSIDY RATE	SUSIDR	.55
PERCENT FINANCED	PF	.75
INTEREST RATE	RATE	.10
CORP. TAX RATE	CTR	.48
INVESTMENT TAX CREDIT	AITC	.07
COST WEIGHTING FACTORS		
FACTOR FOR OUTFIT COST	CCO	1.
FACTOR FOR STEEL COST	CCS	1.
FACTOR FOR MACHINERY C.	CCM	1.
PROGRAM PARAMETERS		
OBJECTIVE SELECTION	IOBJ	1 (NPV)
CONSTRAINT SENSITIVITY PARAMETERS	DELTA(I)	ALL (0)

Table 15 (cont.)

B.I.W. DESIGN

PROGRAM INPUT PARAMETERS

PARAMETER	SYMBOL	VALUE
DESIGN PARAMETERS		
PROPULSIVE COEFFICIENT	PC	.70 (APPENDAGE 1.05)
ENDURANCE	E	12,500.
DISTANCE BETWEEN PORTS	DBP	5,000.
SHIP AVAILABILITY	AVAIL	.98
NUMBER OF SHAFTS	NSHAFT	1
MIN. NO. OF ENGINES*	NENGU	(−)
NO. OF SPARE ENGINES	NEXTRA	0
MAX. PAYLOAD WT.	WW	10,000
MIN. PAYLOAD WT.	WPMIN	0
MAX. CONTAINER STACKING	ND	3
MAX. STACKING ABOVE DK.	MD	6
AVERAGE CONTAINER WT.	WC	11.5
EFFECTIVE CONT. LENGTH	ELENGT	23.0
EFFECTIVE CONT. WIDTH	EWIDTH	8.75
EFFECTIVE CONT. DEPTH	EDEPTH	8.02
DOUBLE BOTTOM THICKNESS	DOUBLE	4.5
BALLAST WEIGHT KG.	KGB	2.5
MAX. SHP FOR SINGLE ENG.	SHPM	N.A.
SEA SPEED FACTOR	BETA1	.0075
SFC FACTOR	BETA2	.365
MISC. WEIGHT	WXX	0
MISC. WEIGHT KG.	XKGX	0
DESIGN WEIGHTING FACTORS		
FACTOR FOR OUTFIT WT.	WWO	1.
FACTOR FOR STEEL WT.	WWS	1.
FACTOR FOR MACHINERY WT	WWM	1.

* NEGATIVE VALUE INDICATES STEAM TURBINE PROPULSION.

 Table 16

B.I.W. (cont)

PROGRAM INPUT PARAMETERS

PARAMETER.	SYMBOL	VALUE
NAVIGATION CONSTRAINTS		
MAX. LENGTH	LENGTM	900. FT.
MAX. BEAM	BEAMM	110. FT.
MAX. DRAFT	DRAFTM	37. FT.
ECONOMIC PARAMETERS		
FREIGHT RATE	FR	50.
PORT CALL FEE	PCF	1000.
DAILY PORT FEE	DPF	1000.
PRICE OF FUEL	PRICE	16.5
ANNUAL INSURANCE RATE	AIR	.1
ASSET LIFE	NN	25
SALVAGE VALUE	SV	0
DISCOUNT FACTOR	DF	.20
SUBSIDY RATE	SUSIDR	.55
PERCENT FINANCED	PF	.75
INTEREST RATE	RATE	.10
CORP. TAX RATE	CTR	.48
INVESTMENT TAX CREDIT	AITC	.07
COST WEIGHTING FACTORS		
FACTOR FOR OUTFIT COST	CCO	1.
FACTOR FOR STEEL COST	CCS	1.
FACTOR FOR MACHINERY C.	CCM	1.
PROGRAM PARAMETERS		
OBJECTIVE SELECTION	IOBJ	1 (NPV)
CONSTRAINT SENSITIVITY PARAMETERS	DELTA(I)	ALL (0)

Table 16 (cont.)

GEORGE G. SHARP DESIGN PROGRAM INPUT PARAMETERS

PARAMETER.	SYMBOL	VALUE
NAVIGATION CONSTRAINTS		
MAX. LENGTH	LENGTM	850
MAX. BEAM	BEAMM	200
MAX. DRAFT	DRAFTM	46
ECONOMIC PARAMETERS		
FREIGHT RATE	FR	50.
PORT CALL FEE	PCF	1000.
DAILY PORT FEE	DPF	1000.
PRICE OF FUEL	PRICE	16.5 *
ANNUAL INSURANCE RATE	AIR	.1
ASSET LIFE	NN	25
SALVAGE VALUE	SV	0
DISCOUNT FACTOR	DF	.20
SUBSIDY RATE	SUSIDR	.55
PERCENT FINANCED	PF	.75
INTEREST RATE	RATE	.10
CORP. TAX RATE	CTR	.48
INVESTMENT TAX CREDIT	AITC	.07
COST WEIGHTING FACTORS		
FACTOR FOR OUTFIT COST	CCO	1
FACTOR FOR STEEL COST	CCS	1
FACTOR FOR MACHINERY C.	CCM	1
PROGRAM PARAMETERS		
OBJECTIVE SELECTION	IOBJ	1 (NPV)
CONSTRAINT SENSITIVITY PARAMETERS	DELTA(I)	ALL (0)

* LOW, ENTERED IN ERROR

Table 17

G. G. S. (CONT)

PROGRAM INPUT PARAMETERS

PARAMETER	SYMBOL	VALUE
DESIGN PARAMETERS		
PROPULSIVE COEFFICIENT	PC	.70 (APPENDAGE 1.05)
ENDURANCE	E	5,000.
DISTANCE BETWEEN PORTS	DBP.	4,800.
SHIP AVAILABILITY	AVAIL	.98
NUMBER OF SHAFTS	NSHAFT	2
MIN. NO. OF ENGINES*	NENGU	2
NO. OF SPARE ENGINES	NEXTRA	0
MAX. PAYLOAD WT.	WW	20000.
MIN. PAYLOAD WT.	WPMIN	0
MAX. CONTAINER STACKING	ND	6
MAX. STACKING ABOVE DK.	MD	3
AVERAGE CONTAINER WT.	WC	20.5
EFFECTIVE CONT. LENGTH	ELENGT	38.0
EFFECTIVE CONT. WIDTH	EWIDTH	8.75
EFFECTIVE CONT. DEPTH	EDEPTH	8.02
DOUBLE BOTTOM THICKNESS	DOUBLE	3.5
BALLAST WEIGHT KG.	KGB	2.0
MAX. SHP FOR SINGLE ENG.	SHPM	18,750
SEA SPEED FACTOR	BETA1	.0075
SFC FACTOR	BETA2	.365
MISC. WEIGHT	WXX	0
MISC. WEIGHT KG.	XKGX	0
DESIGN WEIGHTING FACTORS		
FACTOR FOR OUTFIT WT.	WWO	1.
FACTOR FOR STEEL WT.	WWS	1.
FACTOR FOR MACHINERY WT	WWM	1.

* NEGATIVE VALUE INDICATES STEAM TURBINE PROPULSION.

Table 17 (cont.)

SAMPLE PROBLEM

PROGRAM INPUT PARAMETERS

PARAMETER	SYMBOL	VALUE
DESIGN PARAMETERS		
PROPULSIVE COEFFICIENT	PC	.65
ENDURANCE	E	12,500 NMI
DISTANCE BETWEEN PORTS	DBP	4,800 NMI
SHIP AVAILABILITY	AVAIL	.98
NUMBER OF SHAFTS	NSHAFT	2
MIN. NO. OF ENGINES*	NENGU	2
NO. OF SPARE ENGINES	NEXTRA	0
MAX. PAYLOAD WT.	WW	20,000 TONS
MIN. PAYLOAD WT.	WPMIN	0
MAX. CONTAINER STACKING	ND	6
MAX. STACKING ABOVE DK.	MD	2
AVERAGE CONTAINER WT.	WC	16.5 TONS
EFFECTIVE CONT. LENGTH	ELENGT	23.0 FT.
EFFECTIVE CONT. WIDTH	EWIDTH	8.75 FT
EFFECTIVE CONT. DEPTH	EDEPTH	8.02 FT
DOUBLE BOTTOM THICKNESS	DOUBLE	4.5 FT
BALLAST WEIGHT KG.	KGB	2.5 FT
MAX. SHP FOR SINGLE ENG.	SHPM	24,700 SHP
SEA SPEED FACTOR	BETA1	.0075
SFC FACTOR	BETA2	.365
MISC. WEIGHT	WXX	0.
MISC. WEIGHT KG.	XKGX	0.
DESIGN WEIGHTING FACTORS		
FACTOR FOR OUTFIT WT.	WWO	1.
FACTOR FOR STEEL WT.	WWS	1.
FACTOR FOR MACHINERY WT.	WWM	1.

* NEGATIVE VALUE INDICATES STEAM TURBINE PROPULSION.

Table 18

SAMPLE (CONT)

PROGRAM INPUT PARAMETERS

PARAMETER.	SYMBOL	VALUE
NAVIGATION CONSTRAINTS		
MAX. LENGTH	LENGTM	800. FT
MAX. BEAM	BEAMM	110. FT
MAX. DRAFT	DRAFTM	37. FT.
ECONOMIC PARAMETERS		
FREIGHT RATE	FR	$ 100./TON
PORT CALL FEE	PCF	$ 1000./CALL
DAILY PORT FEE	DPF	$ 1000/DAY
PRICE OF FUEL	PRICE	$ 63.75/TON ‡
ANNUAL INSURANCE RATE	AIR	.01
ASSET LIFE	NN	25. YEARS
SALVAGE VALUE	SV	0
DISCOUNT FACTOR	DF	.20
SUBSIDY RATE	SUSIDR	.55
PERCENT FINANCED	PF	.75
INTEREST RATE	RATE	.10
CORP. TAX RATE	CTR	.48
INVESTMENT TAX CREDIT	AITC	.07
COST WEIGHTING FACTORS		
FACTOR FOR OUTFIT COST	CCO	1.
FACTOR FOR STEEL COST	CCS	1.
FACTOR FOR MACHINERY C.	CCM	1.
PROGRAM PARAMETERS		
OBJECTIVE SELECTION	IOBJ	1 (NPV)
CONSTRAINT SENSITIVITY PARAMETERS	DELTA(I)	ALL (0)

‡ REFLECTS MORE CURRENT TRENDS IN FUEL PRICE (TWICE 1969 LEVEL)

Table 18 (cont.)

Appendix D

USE OF SUMT PROGRAMS

USE OF THE SUMT PROGRAMS

Two programs were developed to obtain the output used during the analysis stage. The first utilizes the SUMT routine to develop attractive alternatives. These alternatives are identified by the values of the decision variables and the objective function. In addition, a second program is available which gives a detailed breakdown of a single design alternative. This second program does not employ any optimization technique. It merely identifies a design in terms of its weights and costs. The inputs for each of these programs are outlined in the next section.

Input Format

The input deck for the SUMT program contains two major elements. The first lists the parameters used by the optimization technique and the second contains the data used by the design model in defining the objective surface. The cards are listed in the order of appearance for the input deck of the SUMT program. (See Figure 25) The second program uses only the design data as its input. See Figure 26.

CARD 1: Problem #1 Parameter Card (See Guide to SUMT)

CARD 2: Initial X_o Vector of Decision Variables
Format (6E12.6)

Displacement; Length; Beam; Draft; Depth
Prismatic Coefficient.

CARD 3: Initial X_o Vector (Continued)
Format (6E12.6)

Velocity.

CARD 4: First Design Card
Format (5F10.2,5X,I2)

Propulsive Coefficient; Endurance; Distance Between Ports; Maximum Shaft Horsepower of a Single Engine; Average Port Delay Time; Maximum Stacking of Containers.

CARD 5: Second Design Data Card
Format (5F10.2,5X,I2)

Maximum Payload Weight; Average Weight of a Container; Effective Container Length; Effective Container Width; Effective Container Depth; Maximum Containers Stacked Above Deck.

CARD 6: Third Design Data Card
Format (5F10.2,5X,I2)

Port Call Fee; Daily Port Fee; Freight Rate; Price of Fuel; Annual Insurance Rate; Indicator of Objective.

CARD 7: Fourth Design Data Card
Format (5F10.2,5X,I2)

Percent Financed; Subsidy Rate; Interest Rate on Loan; Salvage Value of Ship; Discount Factor; Asset Life.

CARD 8: Fifth Design Data Card
Format (5F10.2,5X,I2)

Investment Tax Credit.

CARD 9: Sixth Design Data Card
Format (5F10.2,5X,I2)

Maximum Ship Length; Maximum Ship Beam; Maximum Ship Draft.

CARD 10: Seventh Design Data Card
Format (5F10.2,5X,I2)

Double Bottom Thickness; Center of Gravity of Ballast Weight Above Keel; Ship Availability; Annual Corporate Tax Rate.

CARD 11: Eighth Design Data Card, Sensitivity Data
Format (8F8.2)

Beta1; Beta2; WWO; WWS; WWM; CCO; CCS; CCM.

CARD 12: Ninth Design Data Card
Format (8F8.2)

WXX; XKGX; WPMIN.

CARD 13: Tenth Design Data Card
Format (3I3)

NSHAFT; NENGU; NEXTRA.

CARD 14: Eleventh Design Data Card, Sensitivity Data
Format (14F5.2)

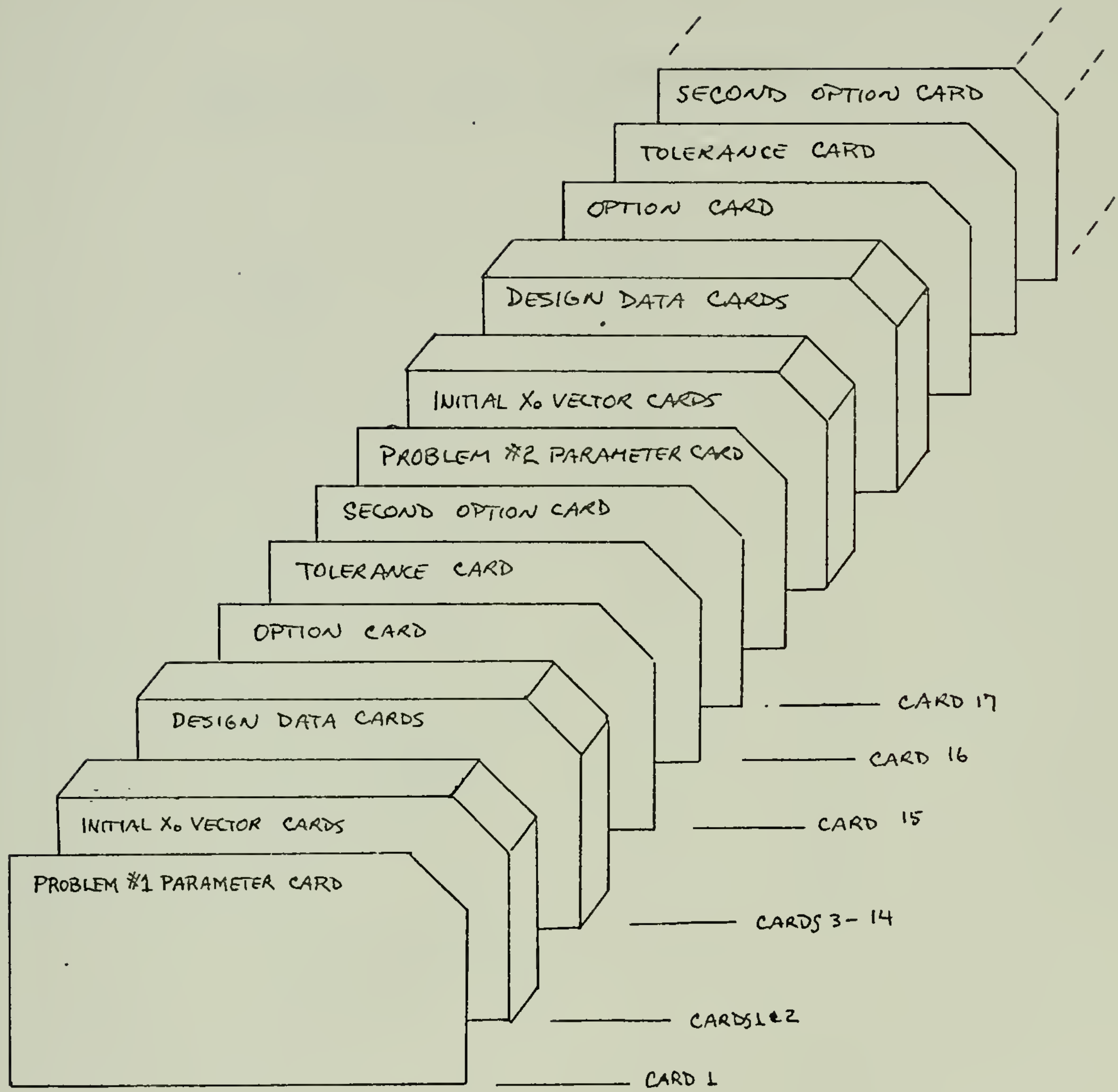
(DELTA(I),I = 1,14)

CARD 15: First Option Card (See Guide to SUMT)

CARD 16: Tolerance Card (See Guide to SUMT)

CARD 17: Second Option Card (See Guide to SUMT)

CARD 18: Problem #2 Parameter Card for Next Program, Repeat Other Cards As Necessary.



PROGRAM DATA DECK STRUCTURE

Figure 24

SAMPLE DATA CARDS FOR SUMT PROGRAM

```
      1.E-5       1.E-0       1.E-4       20.E0       15.    14    7    0
45310.      761.        98.4        33.4        59.6        .692
23.7
      .65     12500.      4800.     24700.        2.      6
  20000.        16.5       23.        8.75       8.02     2
   1000.      1000.       100.       63.75        .1      1
      .75       .55        .10        .00        .15     25
      .07
    900.       110.        37.
     4.5        2.5        .98        .48
000.0075    .265    1.0     1.0    .1.0     1.0     1.0     1.0
  2   2   0
 0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
      3     1     1     1     1     1     1                 1     1
  .0001      -0.0
      1     1
```

Figure 25

SAMPLE DATA CARDS FOR DESIGN MODEL

```
2
32200.     696.        103.       29.5    60.       .548     23.3
 30659.   750.        93.        27.3     55.       .65      25.7
  .78       9000.     5000.    24700.     4.             7
  20000.    11.96      23.        8.75       8.02        3
   1000.    1000.      50.        16.50     .1           1
       .75        .55       .10       .00        .20    25
       .07
    900.       110.       37.
   3.5      2.0       .98       .48
000.0075    .365     .3     1.0     1.0     1.0     1.0     1.0
 0.0     0.0      0.0
 1   0   0
 0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  .72       4800.      4800.     18750.     4.          6
20000.      20.5      38.        8.75       8.02        3
 1000.    1000.        50.       16.50      .1          1
  .75        .55      .10          0.0      .2          25
  .07
  850.       200.      46.
   3.5         2.0       .97      .48
000.0075    .365     .3     1.0     1.0     1.0     1.0     1.0
 0.0     0.0      0.0
  2  2   0
 0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
```

Figure 26

Sample Output

Figure 27 shows the output to the program giving the detailed design.

1. Values of the decision variables.
2. Weight break down of the design.
3. Container configuration.
4. Cash flow statement.
5. Value of objective functions.

Figure 28 shows the output to the SUMT Program. The following annotations apply:

1. The values of the SUMT parameters used for this prob-problem.
2. The initial X_0 vector of decision variables with the associated objective value (F). Also an internal clock is referenced. (Use of design alternative 4)
3. The starting feasible point (same as #2 in this problem)
4. Recording of orthogonal moves made by the routine.
5. The solution to the first subproblem after 10 moves $r = 1.0$.
6. The solution to the second subproblem after 12 moves $r = 1./20$
7. Final solution of the first problem.

```
(1)
DISPL= 0.453100+05  LENGTH= 0.7610+03  BEAM= 0.9840+02  DRAFT= 0.3340+02  DEPTH= 0.5960+02  CP= 0.6920+00  VELOC= 0.2370+02
(2)
BALAST= 0.20249E+04  WP= 0.19288E+05    WO= 0.59711E+04  WS= 0.95830E+04  WM= 0.11287E+04  WF= 0.70137E+04  WX= 0.30000E+03
 GM= 0.80949E+01     TPY= 0.16770E+02   SHPPEQ= 0.56801E+05   ANENG= 0.400E+01
(3) NUMBER OF DECKS= 8      NUMBER OF PARTS OF THE  8TH  DECK IN PLACE = 10
SUBSIDY RATE      PERCENT FINANCED     INTEREST RATE
      0.55000           0.7500000            0.10000
   DISCOUNT FACTOR      CORPORATE TAX RATE
        0.200000             0.480000019
   YEARS            SALVAGE VALUE
    25                  0.0
                                  FR=$200/TON
INITIAL COST =    36667056.0        ANNUAL REVENUE   =    64695056.0         NPV                          RFR
    SUBSIDY =    20166880.0    ANNUAL OPERATING COST =    12114909.0     0.13037E+09                 0.43707E+02
(4)  FINANCE =    12375132.0      ANNUAL LOAN PAYMENT =     1363337.00
 CASH OUTLAY =     2970048.00      ANNUAL TAX PAYMENT =    24267248.0
                                    ANNUAL CASH FLOW =    26949552.0                     (5)
```

Figure 27

Figure 28

```
NONLINEAR PROGRAMMING ROUTINE-SUMT VERSION 4 08/10/71

    N=  7      M= 14      MZ=  0
1
      MAX. TIME= 0.15000000+02    R= 0.10000000+01    RATIO= 0.20000000+02      EPSILON= 0.10000000-04    THETA= 0.10000000-03

OPTIONS SELECTED
    3     1     1     1     1     1     1     0     1     1

TOLERANCES
     0.10000000-03        0.0                      FR= $100/ton        DF= .10

SECOND SET OF OPTIONS
    1     1
    TIME=     0.970 SECONDS
     F= -0.89117410+02      P=  0.0                   G=  0.0                  ASIGMA=  0.0                H=  0.0
2   THE CURRENT VALUE OF A IS
     0.45310000+05        0.74100000+03       0.98400000+02        0.33400000+02        0.59600000+02        0.69200000+00
     0.23700000+02
    THE CONSTRAINT VALUES
                          NOT INCLUDING THE NON-NEGATIVITIES
     0.13469570+03        0.22315440+01       0.13900000+03        0.11600000+02        0.36000000+01        0.34087550+00
     0.35912430+03        0.79999840-02       0.21200000+00        0.80389220+00        0.69610780+00        0.24016120-02
     0.25983970-02        0.60319370-02
    TIME=     0.983 SECONDS

*****THE FEASIBLE STARTING POINT TO BE USED IS ...
     F= -0.89117410+02      P=  0.0                   G=  0.0                  ASIGMA=  0.0                H=  0.0
    THE CURRENT VALUE OF A IS
3    0.45310000+05        0.76100000+03       0.98400000+02        0.33400000+02        0.59A00000+02        0.A9200000+00
     0.23700000+02
    THE CONSTRAINT VALUES
                          NOT INCLUDING THE NON-NEGATIVITIES
     0.13469570+03        0.22315440+01       0.13900000+03        0.11600000+02        0.36000000+01        0.34087530+00
     0.35912430+03        0.79999880-02       0.21200000+00        0.80389220+00        0.69610780+00        0.24016120-02
     0.25943890-02        0.60319370-02

     ORTHOGONAL MOVE

     ORTHOGONAL MOVE

     OATHOGONAL MOVE

     ORTHOGONAL MOVE
4
     ORTHOGONAL MOVE

     ORTHOGONAL MOVE

     ORTHOGONAL MOVE

     ORTHOGONAL MOVE
APPARENTLY ROUNDOFF ERRORS PREVENT A MORE ACCUAATE DETERMINATION OF THE MINIMUM OF THIS SUBPROBLEM.
    TIME=     8.720 SECONDS

*****************************************
        POINT=  11        DOTT=  0.70491320+00      AHO=  0.10000000+01      MAGNITUDE=  0.13115930+05      PHASE= 2
     F= -0.98334480+02      P= -0.12302450+03     G= -0.11933450+03     ASIGMA= -0.21690000+02      H=  0.0
5   THE CURRENT VALUE OF A IS
     0.41323360+05        0.78597340+03       0.96369650+02        0.31940130+02        0.57131710+02        0.69200000+00
     0.21231770+02
    THE CONSTRAINT VALUES
                          NOT INCLUDING THE NON-NEGATIVITIES
```

```
  0.11679550+03     0.12427830+01     0.11402660+03     0.13630350+02     0.50598520+01     0.44267490+00
  0.25732500+00     0.79999500-02     0.21200000+00     0.73280520+00     0.76719480+00     0.30212310-02
  0.19787700-02     0.42273140-01

LAGRANGE MULTIPLIERS
   F= -0.98334480+02    P= -0.12002450+03    G= -0.11933450+03    RSIGMA= -0.21690000+02    H= 0.0
 THE CURRENT VALUE OF X IS
  0.24199560-04     0.12723080-02     0.10376710-01     0.31308560-01     0.17503410-01     0.14450870+01
  0.47099230-01
 THE CONSTRAINT VALUES
                    NOT INCLUDING THE NON-NEGATIVITIES
  0.95619700-02     0.80444600+00     0.87698930-02     0.73365670-01     0.19763420+00     0.22589940+01
  0.38861370+01     0.12500080+03     0.47169810+01     0.13646190+01     0.13034500+01     0.33099090+03
  0.50534440+03     0.23655680+02

  ORTHOGONAL MOVE
APPARENTLY ROUNDOFF ERRORS PREVENT A MORE ACCURATE DETERMINATION OF THE MINIMUM OF THIS SUBPROBLEM.
   TIME=    9.700 SECONDS

*********************************************
6     POINT=  13      DOTT=  0.39326010+10     RHO=  0.50000000-01     MAGNITUDE=  0.13116200+05     PHASE= 2
   F= -0.98334480+02    P= -0.99418950+02    G= -0.99384480+02    RSIGMA= -0.10845000+01    H= 0.0
 THE CURRENT VALUE OF X IS
  0.41323060+05     0.78597340+03     0.96369650+02     0.31940150+02     0.57131710+02     0.69200000+00
  0.21231770+02
 THE CONSTRAINT VALUES
                    NOT INCLUDING THE NON-NEGATIVITIES
  0.11679550+03     0.12427830+01     0.11402660+03     0.13630350+02     0.50598520+01     0.44267490+00
  0.25732500+00     0.79999500-02     0.21200000+00     0.73280520+00     0.76719480+00     0.30212510-02
  0.19787700-02     0.42273140-01

 1ST  ORDER ESTIMATES
   F= -0.98334480+02    P= -0.98334480+02    G= -0.98334480+02    RSIGMA=  0.0                H= 0.0
 THE CURRENT VALUE OF X IS
  0.41323060+05     0.78597340+03     0.96369650+02     0.31940150+02     0.57131710+02     0.69200000+00
  0.21231770+02
 THE CONSTRAINT VALUES
                    NOT INCLUDING THE NON-NEGATIVITIES
  0.11679550+03     0.12427830+01     0.11402660+03     0.13630350+02     0.50598520+01     0.44267490+00
  0.25732500+00     0.79999500-02     0.21200000+00     0.73280520+00     0.76719480+00     0.30212310-02
  0.19787700-02     0.47273140-01

LAGRANGE MULTIPLIERS
   F= -0.98334490+02    P= -0.98334480+02    G= -0.98334480+02    RSIGMA=  0.0                H= 0.0
 THE CURRENT VALUE OF X IS
  0.12099780-05     0.63615380-04     0.51883560-03     0.15654280-02     0.87517070-03     0.72254330-01
  0.23549620-02
 THE CONSTRAINT VALUES
                    NOT INCLUDING THE NON-NEGATIVITIES
  0.42909850-03     0.40232300-01     0.43849420-03     0.34682840-02     0.98817120-02     0.11294970+00
  0.19430680+00     0.62500390+01     0.23584900+00     0.68230950-01     0.65172500-01     0.16549550+02
  0.25268270+02     0.11027840+01

  ORTHOGONAL MOVE
APPARENTLY ROUNDOFF ERRORS PREVENT A MORE ACCURATE DETERMINATION OF THE MINIMUM OF THIS SUBPROBLEM.
   TIME=   10.690 SECONDS

*********************************************
      POINT=  15      DOTT=  0.39326010+10     RHO=  0.25000000-02     MAGNITUDE=  0.13116210+05     PHASE= 2
   F= -0.98334480+02    P= -0.98388710+02    G= -0.98386980+02    RSIGMA= -0.54225010-01    H= 0.0
 THE CURRENT VALUE OF X IS
  0.41323050+05     0.78597320+03     0.96369650+02     0.31940150+02     0.57131710+02     0.69200000+00
  0.21231770+02
```

Figure 28 (cont.)

Figure 28 (cont.)

```
THE CONSTRAINT VALUES
                         NOT INCLUDING THE NON-NEGATIVITIES
 0.1167956D+03        0.1242785D-01        0.1140268D+03        0.1363035D+02        0.5059853D+01        0.4426748D+00
 0.2573250D+00        0.7999950D-02        0.2120000D+00        0.7328051D+00        0.7671949D+00        0.3021230D-02
 0.1978771D-02        0.4227315D-01

 2ND  ORDER ESTIMATES
    F= -0.9833448D+02      P= -0.9833448D+02      G= -0.9833448D+02      ASIGMA=  0.0                H=  0.0
 THE CURRENT VALUE OF X IS
 0.4132335D+05        0.7859732D+03        0.9636965D+02        0.3194015D+02        0.5713171D+02        0.6920000D+00
 0.2123177D+02
 THE CONSTRAINT VALUES
                         NOT INCLUDING THE NON-NEGATIVITIES
 0.1167956D+03        0.1242785D-01        0.1140265D+03        0.1363035D+02        0.5059854D+01        0.4426748D+00
 0.2573250D+00        0.7999950D-02        0.2120000D+00        0.7328051D+00        0.7671949D+00        0.3021230D-02
 0.1978771D-02        0.4227315D-01

 1ST  ORDER ESTIMATES
    F= -0.9833448D+02      P= -0.9833448D+02      G= -0.9833448D+02      ASIGMA=  0.0                H=  0.0
 THE CURRENT VALUE OF X IS
 0.4132305D+05        0.7859732D+03        0.9636965D+02        0.3194015D+02        0.5713171D+02        0.6920000D+00
 0.2123177D+02
 THE CONSTRAINT VALUES
                         NOT INCLUDING THE NON-NEGATIVITIES
 0.1167954D+03        0.1242785D-01        0.1140268D+03        0.1363035D+02        0.5059854D+01        0.4426748D+00
 0.2573250D+00        0.7999950D-02        0.2120000D+00        0.7328051D+00        0.7671949D+00        0.3021230D-02
 0.1978771D-02        0.4227315D-01

LAGRANGE MULTIPLIERS
    F= -0.9833448D+02      P= -0.9833448D+02      G= -0.9833448D+02      RSIGMA=  0.0                H=  0.0
 THE CURRENT VALUE OF X IS
 0.4749893D-07        0.3190779D-05        0.2594178D-04        0.7827140D-04        0.4375853D-04        0.3612717D-02
 0.1177491D-03
 THE CONSTRAINT VALUES
                         NOT INCLUDING THE NON-NEGATIVITIES
 0.2140492D-04        0.2011611D-02        0.2192468D-04        0.1834142D-03        0.4940855D-03        0.5647487D-02
 0.9715340D-02        0.3125020D+00        0.1179245D-01        0.3411548D-02        0.3258624D-02        0.8274775D+00
 0.1263411D+01        0.5913919D-01

  ORTHOGONAL MOVE
APPARENTLY ROUNDOFF ERRORS PREVENT A MORE ACCURATE DETERMINATION OF THE MINIMUM OF THIS SUBPROBLEM.
 TIME=   11.670 SECONDS

*********************************************
      POINT=  17         DOTT=  0.9015290D+12       RHO=  0.1250000D-03      MAGNITUDE=  0.1606378D+05      PHASE= 2
    E= -0.9833446D+02      P= -0.9833718D+02      G= -0.9833709D+02      ASIGMA= -0.2711248D-02      H=  0.0
(7) THE CURRENT VALUE OF X IS
 0.4132309D+05        0.7859733D+03        0.9636965D+02        0.3194018D+02        0.5713168D+02        0.6920000D+00
 0.2123177D+02
 THE CONSTRAINT VALUES
                         NOT INCLUDING THE NON-NEGATIVITIES
 0.1167948D+03        0.1242776D+01        0.1140267D+03        0.1363035D+02        0.5059824D+01        0.4426748D+00
 0.2573250D+00        0.7999949D-02        0.2120000D+00        0.7328079D+00        0.7671921D+00        0.3021228D-02
 0.1978774D-02        0.4227312D-01

 2ND  ORDER ESTIMATES
    F= -0.9833437D+02      P= -0.9833446D+02      G= -0.9833446D+02      RSIGMA=  0.0                H=  0.0
 THE CURRENT VALUE OF X IS
 0.4132309D+05        0.7859733D+03        0.9636965D+02        0.3194018D+02        0.5713167D+02        0.6920000D+00
 0.2123177D+02
 THE CONSTRAINT VALUES
                         NOT INCLUDING THE NON-NEGATIVITIES
```

Figure 28 (cont.)

```
  0.11679480+03      0.12427750+01      0.11402670+03      0.13630350+02      0.50598220+01      0.44267480D+00
  0.25732500+00      0.79999490-02      0.21200000+00      0.73280800+00      0.76719200+00      0.30212270-02
  0.19787740-02      0.42273120-01

 1ST  ORDER ESTIMATES
    F= -0.98334460+02      P= -0.98334460+02      G= -0.98334460D+02     ASIGMA=  0.0                H=  0.0
  THE CURRENT VALUE OF X IS
  0.41323390+05      0.78597330+03      0.96369650+02      0.31940180+02      0.57131670+02      0.69200000+00
  0.21211770+02
  THE CONSTRAINT VALUES
                     NOT INCLUDING THE NON-NEGATIVITIES
  0.11679480+03      0.12427750+01      0.11402670+03      0.13630350+02      0.50598220+01      0.44267480D+00
  0.25732520+00      0.79999490-02      0.21200000+00      0.73280800+00      0.76719200+00      0.30212270-02
  0.19797740-02      0.42273120-01

LAGRANGE MULTIPLIERS
    F= -0.98334460+02      P= -0.98334460+02      G= -0.98334460D+02     ASIGMA=  0.0                H=  0.0
  THE CURRENT VALUE OF X IS
  0.3024 [illegible]30-09      0.15903950-06      0.12970890-05      0.39135660-05      0.21879280-05      0.18063580-03
  0.5937404D-05
  THE CONSTRAINT VALUES
                     NOT INCLUDING THE NON-NEGATIVITIES
  0.13702530-05      0.10058130-03      0.10962340-05      0.91707090-05      0.24704420-04      0.28237430-03
  0.49576700-03      0.15625100-01      0.58962260-03      0.17057680-03      0.16293180-03      0.41373910-01
  0.63170440-01      0.29569610-02
```

Appendix E

SOURCE LISTING OF COMPUTER PROGRAMS

PROGRAM MAIN

Routine that calls design model and outputs a detailed ship design.

Calls subroutines;

READIN
RESTNT

```
C   MAIN PROGRAM TO INTERACT WITH THE DESIGN MODEL
      DOUBLE PRECISION DUM1(93), DUM2(100), DUM3(100,100), VAL,
     1DISPL, LENGT, BEAM, DRAFT, DEPTH, CP, VELOC
      REAL LENGTM,LDR,LBP,LF,LP,LM,KGO,KGS,KGM,KGX,KGR,KP,KGF,
     1MPC,L
      DIMENSION DI(10),L(10),B(10),T(10),D(10),C(10),V(10),VA(10)
      COMMON/SHARE/DISPL,LENGT,BEAM,DRAFT,DEPTH,CP,VELOC,DUM1,
     1DUM2,DUM3,N,M,MN,NP1,NM1
      COMMON/DESIGN/NDECK,NPART,BAL,WP,WO,WS,WM,WX,WF,GMACT,TPY,ANENG
      COMMON/MONEY/PF,SUBSR,RATE,NN,SV,DF,CTR,AITC
      COMMON/FIN/COST1,R,SUBSID,AOC,ANPV,FINAN,PAYMT,CASH1,TPAYMT,
     1CASHA,RFR,CRF
      COMMON/OVAR/LDR,VLR,BDR,LBP,VOL,CV,CB,CM,SHPREQ
      READ (5,55) IN
   55 FORMAT (I2)
      READ (5,101) ((DI(I),L(I),B(I),T(I),D(I),C(I),V(I)),I=1,IN)
  101 FORMAT (7F10.2)
      DO 9999 I=1,IN
      CALL READIN
      DISPL=DI(I)
      LENGT=L(I)
      BEAM=B(I)
      DRAFT=T(I)
      DEPTH=D(I)
      CP=C(I)
      VELOC=V(I)
      WRITE(6,102) DISPL,LENGT,BEAM,DRAFT,DEPTH,CP,VELOC
  102 FORMAT ('1',///,
     1            '  DISPL=',F12.5,'  LENGTH=',F10.3,'  BEAM=',F10.3,
     2'  DRAFT=',F10.3,'  DEPTH=',F10.3,'  CP=',F10.3,'  VELOC=',
     3F10.3)
      J=0
      CALL RESINT (J,VAL)
      WRITE (6,1111) BAL,WP,WO,WS,WM,WF,WX
 1111 FORMAT (//,
```

```
1         '  BALAST=',F12.5,'  WR=',F12.5,'      WO=',F12.5,
2'    WS=',F12.5,'    WM=',F12.5,'    WF=',F12.5,'  WX=',F12.5)
      WRITE (6,1112) GMACT,TRY,SHPREQ,ANENG
1112  FORMAT('    GM=',F12.5,'       TRY=',F12.5,'    SHPREQ=',F12.5,
1'    ANENG=',F10.3)
      WRITE (6,105) NDECK,NDECK,NPART
 105  FORMAT ('    NUMBER OF DECKS=',I2,5X,'  NUMBER OF PARTS OF THE ',
1I2,'TH  DECK IN PLACE = ',I2)
      WRITE (6,900) SUBSR,PF, RATE
      WRITE (6,901) DF,CTR,NN,SV

      WRITE (6,910) COST1,R,SUBSID,AOC,ANPV,CRF,PFR
      CASH1=-CASH1
      WRITE (6,911) FINAN,PAYMT,CASH1,TRAYMT,CASHA
 900  FORMAT (5X,/,
1' SUBSIDY RATE',5X,' PERCENT FINANCED',5X,'INTEREST RATE',/,
25X,F13.5,5X,F17.7,5X,F13.5)
 901  FORMAT (5X,' DISCOUNT FACTOR',5X,' CORPORATE TAX RATE',/,5X,
1F16.6,5X,F19.9,'  ',/ ,5X,' YEARS',10X,' SALVAGE VALUE',
2/,5X,I4,7X,F14.2)
 910  FORMAT (' ',/,' INITIAL COST = ',F14.2, 9X,' ANNUAL REVENUE  = ',
1F14.2,10X,'NPV',15X,'CRF',15X,'PFR',/,5X,' SUBSIDY = ',F14.2,3X,
2' ANNUAL OPERATING COST = ',F14.2,5X,F12.5,5X,F12.5,5X,F12.5)
 911  FORMAT (5X,' FINANCE = ',F14.2,5X,' ANNUAL LOAN PAYMENT = ',
1F14.2  ,/,'  CASH OUTLAY = ',F14.2,7X,'ANNUAL TAX PAYMENT = ',
2F14.2,/,  38X,' ANNUAL CASH FLOW = ',F14.2)
9999  CONTINUE
      STOP
      END
```

SUBROUTINES USED IN SUMT PROGRAM

includes routines

READIN

RESTNT

GRAD1

MATRIX

Note:

Subroutine RESTNT Calls

Subroutine Object

```
      SUBROUTINE READIN
      REAL L,LENGT,LENGTM,LDR,LBR,LF,LP,LM,KGO,KGS,KGM,KGX,KGB,KB,KGF,
     1NEC
      COMMON/SHP/ CR(6210), CPS(10), CTS(10), CFS(10), ETAD(10),
     1PE(10), P(10), VL(10), PS(10), UOB(10)
      COMMON/PARAM/PC,F,DBP,SHPM,TD,WW,ND,WC,ELENGT,FWIDTH,FDEPTH,MD,
     1PCF,DPF,FP,PRICE,AIR,AVAIL,IROJ
      COMMON/MONEY/PF,SUBSP,RATE,NN,SV,DF,CTR,AITC
      COMMON/HULL/ DOUBLE,KGB
      COMMON/NAV/LENGTM,BEAMM,DRAFTM
      COMMON/CHANG/BETA1,BETA2,WWO,WWS,WWM,CCS,CCO,CCM,NSHAFT,NENGU,
     1NEXTRA,WXX,XKGX,WRMIN
      COMMON/DELT/DELTA(20)
      READ (5,1120) PC,F,DBP,SHPM,TD,ND,WW,WC,ELENGT,FWIDTH,FDEPTH,MD,
     1PCF,DPF,FP,PRICE,AIR,IROJ
      READ (5,1120) PF,SUBSP,RATE,SV,DF,NN,AITC
 1120 FORMAT (5F10.2,5X,I2)
      READ (5,1120) LENGTM,BEAMM,DRAFTM
      READ (5,1120) DOUBLE,KGB,AVAIL,CTR
      READ (5,1121) BETA1,BETA2,WWO,WWS,WWM,CCO,CCS,CCM
      READ(5,1121) WXX,XKGX,WRMIN
 1121 FORMAT (8F8.2)
      READ (5,1123) NSHAFT,NENGU,NEXTRA
 1123 FORMAT (3I2)
      READ (5,1122) (DELTA(I),I=1,14)
 1122 FORMAT (14F5.2)
      READ (9,1001) (CR(I),I=1,6210)
 1001 FORMAT (13F4.2)
      REWIND 9
      RETURN
      END
```

```
      SUBROUTINE DESTNT (IN,VAL)
C  THIS ROUTINE EVALUATES THE OBJECTIVE FUNCTION AND THE CONSTRAINTS
C  FOR A GIVEN VALUE OF THE X VECTOR.
      DOUBLE PRECISION DUM(93), DEL(100), A(100,100), VAL,
     1DISPL , LENGT, BEAM, DRAFT, DEPTH, CP, VELOC
      REAL LENGTM,LDR,LBP,LF,LP,LM,KGO,KGS,KGM,KGX,KGB,KB,KGF,
     1MBC
      COMMON/SHARE/DISPL ,LENGT,BEAM,DRAFT,DEPTH,CP,VELOC,DUM1,
     1DUM2,DUM3,N,M,MN,NP1,NM1
      COMMON/MONEY/PF,SUBSP,RATE,NN,SV,DF,CTP,AITC
      COMMON/OVAR/LDR,VLR,BDR,LBP,VOL,CV,CB,CM,SHPREQ
      COMMON/NAV/LENGTM,BEAMM,DRAFTM
      COMMON/DELT/DELTA(20)
      IF (IN) 5,5,9
    5 CONTINUE
C  CALCULATE F(X)
      CALL OBJECT(VAL)
      RETURN
C  CALCULATE G(X)
    9 GO TO (10,20,30,40,50,60,70,80,90,100,110,120,130,140),IN
C  GM CONSTRAINT HANDLED INTERNALLY
C  CONSTRAINT DUE TO FREEBOARD
   10 IF (LENGT.GE.400.) GO TO 11
C  LENGTH LESS THAN 400 FT.
      FBRQ=4.21+3.59*LENGT/100.+3.71*(LENGT/100.)**2
      GO TO 13
   11 IF (LENGT.GE.750.) GO TO 12
C  LENGTH GREATER THAN 400 FT. BUT LESS THAN 750 FT.
      FBRQ=-77.67+42.58*LENGT/100.-.6*(LENGT/100.)**2-.08*
     1(LENGT/100.)**3
      GO TO 13
   12 CONTINUE
C  LENGTH GREATER THAN 750 FT.
      FBRQ=.2322*LENGT
   13 CONTINUE
```

(2)

```
      FRACT=12.*(DEPTH-(.25+DRAFT))
      VAL=FRACT-FRRO
      VAL=VAL+DELTA(IN)
      RETURN
C   STRENGTH CONSTRAINT
   20 VAL=15.-LENGT/DEPTH
      VAL=VAL+DELTA(IN)
      RETURN
C   NAVIGATION RESTRICTIONS
   30 VAL=LENGTM-LENGT
      VAL=VAL+DELTA(IN)
      RETURN
   40 VAL=BEAMM-BEAM
      VAL=VAL+DELTA(IN)
      RETURN
   50 VAL=DRAFTM-DRAFT
      VAL=VAL+DELTA(IN)
      RETURN
C   DATA RESTRICTION
C   MOST ARE HANDLED INTERNALLY IN SHP CALCULATION BY ASSIGNING PENALTY
C   OTHER RESTRICTIONS ON COEFFICIENTS
   60 VAL=1.2-VELOC/DSQRT(LENGT)
      VAL=VAL+DELTA(IN)
      RETURN
   70 VAL=VELOC/DSQRT(LENGT)-.5
      VAL=VAL+DELTA(IN)
      RETURN
   80 VAL=.7-CP
      VAL=VAL+DELTA(IN)
      RETURN
```

```
 90 VAL=CP-.43
    VAL=VAL+DELTA(IN)
    RETURN
100 VAL=3.75-BEAM/DRAFT
    VAL=VAL+DELTA(IN)
    RETURN
110 VAL=BEAM/DRAFT-2.25
    VAL=VAL+DELTA(IN)
    RETURN
120 VAL=.006-35.*DISPL/(LENGT**3)
    VAL=VAL+DELTA(IN)
    RETURN
130 VAL=35.*DISPL/(LENGT**3)-.001
    VAL=VAL+DELTA(IN)
    RETURN
140 VAL=(.925+DELTA(14))*CP-35.*DISPL/(LENGT*BEAM*DRAFT)
    RETURN
    END
```

```
      SUBROUTINE GRAD1 (IN)
C  THIS CALCULATES THE DERIVATIVES OF THE FUNCTIONS AT A SINGLE POINT
      DOUBLE PRECISION DUM1(93), DEL(100), DUM3(100,100), VAL ,
     1DISPL , LENGT, BEAM, DRAFT, DEPTH, CP, VELOC
      REAL LENGTM,LDR,LBR,LE,LP,LM,KGO,KGS,KGM,KGX,KGB,KB,KGF,
     1MRC
      COMMON/SHARE/DISPL,LENGT,BEAM,DRAFT,DEPTH,CP,VELOC,DUM1,
     1DEL,DUM3,N,M,MN,NP1NM1
      COMMON/DELT/DELTA(20)
      FOX(AA,NB,NC,ND,NE,NF,NG)=AA*(DISPL**NB)*(LENGT**NC)*(BEAM**ND)*
     1(DRAFT**NE)*(DEPTH**NF)*(CP**NG)
      IF (IN) 5,5,9
    5 CONTINUE
      CALL DIFF1(0)
      RETURN
C  CALCULATE DERIVATIVE OF G(X) AT X
C  DETERMINATION OF DEL(J) FOR GRAD1 SUBROUTINE
    9 CONTINUE
      DO 101 J=1,7
  101 DEL(J)=0.0
      GO TO (10,20,30,40,50,60,70,80,90,100,110,120,130,140),IN
   10 CONTINUE
      DEL(4)=-12.
      DEL(5)=+12.
      IF (LENGT.GE.400.) GO TO 11
C  LENGTH LESS THAN 400 FT.
      DEL(2)=.0359+.0742*LENGT
      GO TO 13
   11 IF (LENGT.GE.750.) GO TO 12
C  LENGTH GREATER THAN 400 FT. BUT LESS THAN 750 FT.
      DEL(2)=.4258-.012*LENGT-.24*(LENGT/100.)**2
      GO TO 13
   12 CONTINUE
C  LENGTH GREATER THAN 750 FT.
      DEL(2)=.2322
```

```
13  CONTINUE
    RETURN
20  DEL(2)=-1.*DEPTH**(-1)
    DEL(5)=FOX(1.,0.1,0.0,-2,0)
    RETURN
30  DEL(2)=-1.
    RETURN
40  DEL(3)=-1.
    RETURN
50  DEL(4)=-1.
    RETURN
60  CONTINUE
    DEL(2)=+.5*VELOC/(DSQRT(LENGT)**3)
    DEL(7)=-1./DSQRT(LENGT)
    RETURN
70  CONTINUE
    DEL(2)=-.5*VELOC/(DSQRT(LENGT)**3)
    DEL(7)=+1./DSQRT(LENGT)
    RETURN
80  DEL(6)=-1.
    RETURN
90  DEL(6)=1.
    RETURN
100 DEL(3)=-1./DRAFT
    DEL(4)= BEAM*DRAFT**(-2)
    RETURN
```

```
110 DEL(3)=1./DRAFT
    DEL(4)=-1.*BEAM/DRAFT**(2)
    RETURN
120 DEL(1)= -35.*LENGT**(-3)
    DEL(2)=105.*DISPL*LENGT**(-4)
    RETURN
130 DEL(1)=35.*LENGT**(-3)
    DEL(2)=-105.*DISPL*LENGT**(-4)
    RETURN
C   LENGTH GREATER THAN 750 FT.
    J=1
 13 CONTINUE
    RETURN
140 CONTINUE
    DEL(1)=FOX(-35.,0.-1.-1.-1.0.0)
    DEL(2)=FOX(+35.,1,-2,-1.-1.0.0)
    DEL(3)=FOX(+35.,1.-1.-2.-1.0.0)
    DEL(4)=FOX(+35.,1.-1.-1.-2.0.0)
    DEL(6)=.325*DELTA(14)
    RETURN
    END
```

```
      SUBROUTINE MATRIX(IN, J)
C  THIS CALCULATED THE SECOND DERIVATIVES OF THE FUNCTIONS
      DOUBLE PRECISION DUM1(93), DUM2(100), A(100,100), VAL,
     1DISPL , LENGT, BEAM, DRAFT, DEPTH, CP, VELOC
      REAL LENGTM,LDR,LBR,LF,LP,LM,KGO,KGS,KGM,KGX,KGB,KB,KGF,
     1MRC
      COMMON/SHAPE/DISPL,LENGT,BEAM,DRAFT,DEPTH,CP,VELOC,DUM1,
     1DUM2,A,N,M,MN,NP1,NM1
      COMMON/DELT/DELTA(20)
      FOX(AA,NB,NC,ND,NE,NF,NG)=AA*(DISPL**NB)*(LENGT**NC)*(BEAM**ND)*
     1(DRAFT**NE)*(DEPTH**NF)*(CP**NG)
      IF (IN) 5,5,9
    5 CONTINUE
C  CALCULATE SECOND DERIVATIIVES OF F(2) AT X
      CALL DIFF2(0)
      RETURN
    9 GO TO (10,20,30,30,30,60,70,30,30,100,110,120,130,140),IN
   10 CONTINUE
      IF (LENGT.GE.400.) GO TO 11
C  LENGTH LESS THAN 400 FT.
      A(2,2)=.0742
      GO TO 13
   11 IF (LENGT.GE.750.) GO TO 12
C  LENGTH GREATER THAN 400 FT. BUT LESS THAN 750 FT.
      A(2,2)=-.012-.0048*LENGT
      GO TO 13
   12 CONTINUE
   20 A(2,5)=DEPTH**(-2)
      A(5,5)=-2.*LENGT*(DEPTH**(-3))
      RETURN
   30 J=1
      RETURN
   60 CONTINUE
      A(2,2)=-.75*VELOC/(DSQRT(LENGT)**5)
      A(2,7)=+.5*VELOC/(DSQRT(LENGT)**3)
```

```
      RETURN
   70 CONTINUE
      A(2,2)=+.75*VELOC/(DSQRT(LENGT)**5)
      A(2,7)=-.5*VELOC/(DSQRT(LENGT)**3)
      RETURN
  100 A(3,4)=FOX(1.,0,0,0,-2,0,0)
      A(4,4)=FOX(-2.,0,0,1,-3,0,0)
      RETURN
  110 A(3,4)=FOX(-1.,0,0,0,-2,0,0)
      A(4,4)=FOX(2.,0,0,1,-3,0,0)
      RETURN
  120 A(1,2)=FOX(105.,0,-4,0,0,0,0)
      A(2,2)=FOX(-420.,1,-5,0,0,0,0)
      RETURN
  130 A(1,2)=FOX(-105.,0,-4,0,0,0,0)
      A(2,2)=FOX(420.,1,-5,0,0,0,0)
      RETURN
  140 CONTINUE
      A(1,2)=FOX(+35.,0,-2,-1,-1,0,0)
      A(1,3)=FOX(+35.,0,-1,-2,-1,0,0)
      A(1,4)=FOX(+35.,0,-1,-1,-2,0,0)
      A(2,2)=FOX(-70.,1,-3,-1,-1,0,0)
      A(2,3)=FOX(-35.,1,-2,-2,-1,0,0)
      A(2,4)=FOX(-35.,1,-2,-1,-2,0,0)
      A(3,3)=FOX(-70.,1,-1,-3,-1,0,0)
      A(3,4)=FOX(-35.,1,-1,-2,-2,0,0)
      A(4,4)=FOX(-70.,1,-1,-1,-3,0,0)
      RETURN
      END
```

SHIP DESIGN PROGRAMS

includes subroutines

OBJECT

SHPREQ

RESIS

Notes:

Subroutine object calls subroutine SHPRQ

Subroutine SHPRQ calls subroutine RESIS

```
      SUBROUTINE OBJECT(VAL)
      DOUBLE PRECISION DUM1(93), DUM2(100), DUM3(100,100), VAL,
     1DISPL, LENGT, BEAM, DRAFT, DEPTH, CP, VELOC
      REAL LENGTM,LDR,LBR,LF,LP,LM,KGO,KGS,KGM,KGX,KGR,KB,KGF,
     1MBC
      DIMENSION SHPMAX(10),WPP(10,10),WPPKG(10,10)
      COMMON/DESIGN/NDECK,NPART,BAL,WP,WO,WS,WM,WX,WF,GMACT,TPY,ANENG
      COMMON/FIN/COST1,R,SUBSID,AOC,ANPV,FINAN,PAYMT,CASH1,TPAYMT,
     1CASHA,BER,CRF
      COMMON/PARAM/PC,F,DBP,SHPM,TD,WW,ND,WC,ELENGT,EWIDTH,EDEPTH,MD,
     1PCF,DPF,FP,PRICE,AIR,AVAIL,IBOJ
      COMMON/MONEY/PF,SUBSR,RATE,NN,SV,DF,CTR,AITC
      COMMON/SHARE/DISPL,LENGT,BEAM,DRAFT,DEPTH,CP,VELOC,DUM1,
     1DUM2,DUM3,N,M,MN,NP1,NM1
      COMMON/OVAR/LDR,VLR,BDR,LBR,VOL,CV,CB,CM,SHPREQ
      COMMON/PUTIN/ GNU,GAMMA,NVEL,DCF,NER
      COMMON/HULL/ DOUBLE,KGB
      COMMON/CHANG/BETA1,BETA2,WWO,WWS,WWM,CCS,CCO,CCM,NSHAFT,NENGU,
     1NEXTRA,WXX,XKGX,WPMIN
C   DEFINITION OF INPUT VARIABLES
C      DISPLVDISPLACEMENT                  VELOC=VELOCITY
C      LENGT=LENGTH                        BEAM=BEAM
C      DRAFT=DRAFT                         DEPTH=DEPTH
C      CP    =PRISMATIC COEFFICIENT OF FORM
C   DETERMINATION OF DEPENDENT VARIABLES
C   DEFINITION
C      LDR=LENGTH-DRAFT RATIO
C      VLR=VELOCITY-LENGTH RATIO
C      BDR=BEAM-DRAFT RATIO
C      LBR=LENGTH-BEAM RATIO
C      VOL=VOLUME (UNDERWATER)
C      CV =VOLUMETRIC COEFFICIENT
C      CB =BLOCK COEFFICIENT
C      CM =MIDSHIP COEFFICIENT
      LDR=LENGT/DRAFT
```

```
          CONST=LENGT
(23)      VLR=VELOC/SQRT(CONST)
          BDR=BEAM/DRAFT
(22)      LBR=LENGT/BEAM
          VOL=35.*DISPL
(21)      CV=VOL/(LENGT**3)
          CB=VOL/(LENGT*BEAM*DRAFT)
          CM=CB/CP
C   CALCULATE VELOCITY MADE GOOD IN THE SEAWAY (VELOCS)
(24) C   CALCULATION OF VELOCS
          CONST=VELOC
          VELOCS=VELOC*(2.-EXP(BETA1*CONST))
C   SUBPROGRAM THAT USES THE TAYLOR STANDERD SERIES
C   PACKAGE TO DETERMINE THE SHP   REQUIRED OF A GIVEN DESIGN  (SHPRQ)
C   INPUT DATA SHPM
          SHPMAX(1)=SHPM
          DO 10 I=1,10
          AI=I
          SHPMAX(I)=AI*SHPMAX(1)
   10 CONTINUE
C   INPUT CONSTANTS FOR THE PROBLEM
          GNU=.000012615
          GAMMA=1./35.
          NVEL=1
          DCF=.0004
(25)      CALL SHPRQ
C   TEST FOR NUMBER OF SHAFTS
(26)      GO TO (1551,1552), NSHAFT
C   ONE SHAFT
 1551 APPEND=1.07
          SHPREQ=SHPREQ*APPEND
C   TEST FOR STEAM PLANT
          IF (NENGU.LE.0) GO TO 2345
          J=SHPREQ/SHPMAX(1)+.999
          I=J-NENGU
```

```
      I=(I-IABS(I))/2
      J=J-I
      ANENG=J+NEXTRA
      GO TO 1553
C   TWO SHAFTS
 1552 APPEND=1.15
      SHPREQ=SHPREQ*APPEND
C   TEST FOR STEAM PLANT
      IF (NENGU.LE.0) GO TO 2345
      J=SHPREQ/SHPMAX(1)+.999
      I=J-NENGU
      I=(I-IABS(I))/2
      J=J-I
      ANUM=J
      NAN=ANUM/2.
      NPAP=2*NAN
      APAP=NPAP
      ITEST=ANUM-APAP
      IF (ITEST) 1332,1332,1331
 1331 J=J+1
(26) 1332 ANENG=J+NEXTRA
 1553 CONTINUE
C   ASSUME SFC BEST
(28)  SFCB=.42
      SFC=SFCB*((SHPREQ/SHPMAX(J))**(-BETA2))
(29)  FC=SFC*SHPREQ
      GO TO 4321
 2345 CONTINUE
C   ADJUSTMENT FOR STEAM PLANT
      ANENG=1.
(29') FC=(.5*SHPREQ)/(SHPREQ-855.)*SHPREQ
      SHPREQ=SHPREQ/.8
 4321 CONTINUE
(4) C   CALCULATION OF OUTFIT WIEGHT (WO)
      WO=.15*(.986*LENGT*BEAM/100.)**1.6
```

```
          WO=WWO*WO
(5)  C   CALCULATION OF STEEL WEIGHT (WS)
          WS=2.107*(.986*LENGT*(BEAM+DEPTH)/100.)**1.19
          WS=WWS*WS
     C   CALCULATION OF MACHINERY WEIGHT (WM)
     C   TEST FOR TYPE ENGINE
          IF(NENGU.LE.0) GO TO 7662
(3)  C   MACHINERY WEIGHT FOR GAS TURBINE PLANT
          WM=3.85*SHPREQ/1000.+730.+60.*(ANENG-1.)
          WM=WWM*WM
          GO TO 6772
 7662 CONTINUE
(3)  C   MACHINERY WEIGHT FOR STEAM PLANT
          WM=7.18*(SHPREQ)**.495
          WM=WWM*WM
 6772 CONTINUE
(6)  C   CALCULATION OF MISC. WEIGHT (WX)
          WX=300.+WXY
     C   CALCULATION OF FUEL WEIGHT (WF)
     C   FUEL CONSUMPTION (FC) DETERMINED EARLIER AND VELOCS ALSO
     C   ASSUME VALUES FOR
     C   DATA FROM SCENERIO  ENDURANCE, ENDURANCE SPEED
     C      E=ENDURANCE DISTANCE
     C      VELOCE=ENDURANCE VELOCITY
     C   THIS MODEL ASSUMES 10 PER CENT RESERVE FUEL OVER THAT REQUIRED
     C   FOR THE TRANSIT AND THE VELOCITY FOR THE ENDURANCE CALCULATION WILL
     C   BE ASSUMED TO BE THE SAME AS THE SERVICE VELOCITY MADE GOOD IN
     C   OPEN WATER DURING THE TRANSIT
(20)      WF=(1.1*E)*FC/(2240.*VELOCS)
     C   CALCULATE NUMBER OF ROUND TRIPS PER YEAR (TPY)
     C   GIVEN AVAILABILITY WHICH IS A FUNCTION OF RELIABILITY (AVAIL)
     C   GIVEN AVERAGE DELAY TIME INPOR---COULD BE CETERMINED FROM THE
     C   LOADING BUT WE WILL ASSUME A CONSTANT VALUE WHICH REFLECTS A
     C   CERTAIN NUMBER OF HIGH TIDES
     C   GIVEN THE DISTANCE BETWEEN PORTS (DBP)
```

```
(27) C   AVERAGE DELAY TIME INPORT = TD
            CONST=2.*(DBP/VELOCS)+TD)
            TPY=(360.*24*AVAIL)/CONST
     C   CALCULATE YEARLY FUEL CONSUMPTION (YFC)
     C   ASSUME ALL FUEL CONSUMED AT VELOC AND SHPREQ
(32)        YFC= TPY * 2.* DBP * FC/(2240 * VELOCS)
     C   CALCULATE ANNUAL REVENUES
     C   CALCULATION OF AVAILABLE PAYLOAD WEIGHT (APW)
(15)        APW=DISPL-WO-WS-WM-WF-WX
            RAL=0.
     C   CALCULATION OF CENTER OF GRAVITY FOR OUTFIT WEIGHT (KGO)
(9)         KGO=1.*DEPTH
     C   CALCULATION OF CENTER OF GRAVITY FOR STEEL WEIGHT (KGS)
(10)        KGS=.61*DEPTH
     C   CALCULATION OF CENTER OF GRAVITY FOR MACHINERY WEIGHT (KGM)
     C   ASSUMED SIMILAR TO A STEAM PLANT
(8)         KGM=.55*DEPTH
     C   CALCULATION OF CENTER OF GRAVITY FOR MISC. WEIGHT (KGX)
(11)        KGX=1.*DEPTH+WXX*XKGX/WX
     C   CALCULATE CENTER OF GRAVITY OF FUEL
(7)         KGF=.68*DOUBLE
     C   CALCULATE WATERPLANE INERTIA COEFFICIENT (ALPHA)
(12)        ALPHA=.0957*CP-.0122
     C   CALCULATE BM
(17)        BM=(ALPHA*LENGT*BEAM**3)/VOL
     C   CALCULATE CONTER OF BOUYANCY (KB)
(14)        KB=.54*DRAFT
     C   ASSUME GM REQUIRED (MIN)
(13)        GMREQ=.05*BEAM
     C   CALCULATION OF AVAILABLE RIGHTING MOMENT FOR PAYLOAD DUE TO
(16')C   THE NEED TO MAINTAIN AVAILABLE GM AS REQUIRED
            CONSTT=WO*KGO+WS*KGS+WM*KGM+WX*KGX+WF*KGF
(18)        RMMAX=DISPL*(KB+BM-GMREQ)-CONSTT
     C   INPUT CONTAINER SIZES (INCLUDE CLEARANCES)
     C      ELENGT=EFFECTIVE LENGTH OF A CONTAINER
```

```
C     EWIDTH=EFFECTIVE WIDTH OF A CONTAINER
C     EDEPTH=EFFECTIVE DEPTH OF A CONTAINER
C   DETERMINE
C     LE=EFFECTIVE LENGTH OF THE STORAGE SPACE FOR THE CONTAINERS
C     BE=EFFECTIVE BEAM FOR THE STORAGE OF THE CONTAINERS
C     DE=EFFECTIVE DEPTH FOR THE STORAGE OF CONTAINERS
C   CALCULATION OF EFFECTIVE LENGTHS FOR THE STORAGE OF CONTAINERS
      LP=.09*LENGT
      LM=60.+SHPREC/1000.
      LE=LENGT-LP-LM
C   ASSUME A WING TANK SIZE
      WINGT=.20*BEAM
      BE=BEAM-WINGT
      DE=DEPTH-DOUBLE
C DETERMINE MATRIX OF WEIGHTS AND RIGHTING MOMENTS
C   INPUT AVERAGE WEIGHT OF THE CONTAINERS (WC)
C   INPUT THE DOUBLE BOTTOM THICKNESX
C   ASSUME A CENTER OF GRAVITY FOR THE WEIGHT IN THE CONTAINER
C   IN THIS CASE IT IS ASSUMED TO BE 1/2 EDEPTH
C   ASSUME A MAXIMUM NUMBER OF DECKS INTERIOR  = N
C   ASSUME A MAXIMUM NUMBER OF DECKS TOPSIDE = M
C   LET K DENOTE THE DECK INVOLVED
C   THE FIRST DECT WILL TAKE INTO ACCOUNT ALL CONTAINERS
C   BELOW THE WATER LINE
C   THE WEIGHTS ARE ADDED ONE AT A TIME.  SO THAT
C   SO THAT ONE TENTH OF THE WIEGHT OF THE DECK WILL BE PLACED AT A
C   TIME AND THE DECKS MUST BE FILLED SEQUENTIALLY
      NLE=LE/FLENGT
      NBE=BE/EWIDTH
      NDE=DE/EDEPTH
      ALE=NLE
      ABE=NBE
      ADE=NDE
      NUMB=(DRAFT-DOUBLE)/EDEPTH
      IF (ND.LE.NDE) GO TO 44
```

```
      ND=NDE
   44 CONTINUE
      IF (NUMB.LE.ND) GO TO 61
      NUMB=ND
   61 CONTINUE
      K=1
      ANUMB=NUMB
      CONST=NUMB*EDEPTH
      NK=ALE*ABE*ANUMB*CP
      WPK=ND
      ANK=NK
      WPK=ANK*WC/10.
      WPKGK=(.55*CONST+DOUBLE)*WPK
      DO 51 J=1,10
      WPP(K,J)=WPK
      WPPKG(K,J)=WPKGK
   51 CONTINUE
      IF (NUMB.LT.2) GO TO 62
      DO 52 K=2,NUMB
      DO 52 J=1,10
      WPP(K,J)=0.
      WPPKG(K,J)=0.
   52 CONTINUE
   62 CONTINUE
C  DETERMINATION OF THE COEFFICIENT OF WATERPLANE AREA AS RELATED TO CP
      CWP=CP+.10
      NUMB=NUMB+1
      NK=ALE*ABE*CWP
      ANK=NK
      WPK=ANK*WC/10.
      IF (NUMB.GT.ND) GO TO 63
      DO 53 K=NUMB,ND
      AK=K
      WPKGK=(DOUBLE+(AK-.5)*EDEPTH)*WPK
      DO 53 J=1,10
```

```
      WPP(K,J)=WPK
      WPPKG(K,J)=WPKGK
   53 CONTINUE
   63 CONTINUE
      NND=ND+1
      MM=MD+ND
C  SAME WPK ABOVE DECK THAT IS THE SAME NUMBER PER LEVEL
      IF(MD.LT.1) GO TO 55
      DO 54 K=NND,MM
      AK=K
      AN=ND
      WPKGK=(DEPTH+((AK-AN)-.5)*FDEPTH)*WPK
      DO 54 J=1,10
      WPP(K,J)=WPK
      WPPKG(K,J)=WPKGK
   54 CONTINUE
   55 CONTINUE
C  DETERMINE PAYLOAD (WP) OF THE DESIGN ALTERNATIVE
C  INPUT FROM OTHER PARTS OF THE PROGRAM
C     MAXIMUM WEIGHT AVAILABLE FOR THE PAYLOAD = WPMAX
C     MAXIMUM RIGHTING MOMENT AVAILABLE         = RMMAX
      WPMAX=APW
      NDECK=0.
      NPART=0.
      IF (WPMAX.GE.WPMIN) GO TO 21
C  PENALTY FUNCTION
C  ASSIGN A COST CONSISTANT WITH THE FREIGHT RATE
44'   P=FR*(-1.)*ABS(WPMAX)
      GO TO 85
   21 CONTINUE
C     KGBAL= CENTEROF GRAVITY OF THE BALAST
      WPKG=WPMAX*KGB
      IF (RMMAX.GT.WPKG) GO TO 20
C  ASSIGN A PENALTY COST
44'   P=0.
```

```
      GO TO 85
   20 CONTINUE
      WP=0.
      BALF=0.
      IF (WPMAX.LT.WW) GO TO 333
      BALF=WPMAX-WW
  333 BAL=WPMAX
      DO 73 K=1,MM
      DO 73 J=1,10
      WP=WP+WPP(K,J)
      BAL=BAL-WPP(K,J)
      IF (BAL.LT.BALF) GO TO 65
      WPKG=WPKG-WPP(K,J)*KGP+WPPKG(K,J)
      IF (WPKG.GT.PMMAX) GO TO 65
      NDECK=K
      NPART=J
   73 CONTINUE
      GO TO 84
   65 CONTINUE
      WP=WP-WPP(K,J)
      WPKG=WPKG+WPP(K,J)*KGP-WPPKG(K,J)
      BAL=BAL+WPP(K,J)
      NDECK=K
      NPART=J-1
   84 CONTINUE
C     GIVEN THE FREIGHT RATE CGARGED IN DOLLARS PER TON
(44) C     ASSUME AVERAGE WEIGHTS FOR DESIGHN PERPOSES
      R=FR*(TRY*WP)
(19)   85 CONTINUE
      WP=BAL
C     CALCULATE ACTUAL GM
(1)       GMACT=KB+BM-(WPKG+BAL*KGP+CONSTT)/DISPL
C     CALCULATION OF INITIAL COST OF BUILDING DESIGN ALTERNATIVE (COSTI)
C     DEFINITION OF VARIABLES
C         STEELE COSTS          =COSTS
```

```
C      MACHINERY COSTS     =COSTM
C      OUTAGE COSTS        =COSTO
C      BALLAST COSTS       =COSTB
(36) C   CALCULATION OF STEEL COST (CS)
       A=WS/1000.
       B=A*A
       C=A*B
       CS=WS*(218.4-21.38*A+2.061*B-.1149*C)*
      1(5.)
       CS=CCS*CS
(35) C   CALCULATION OF OUTFIT COST (CO)
       IF (WO.GT.1400.) GO TO 111
C   WO GREATER THAN ZERO BUT LESS THAN 1400.
       CO=WO*(1100.-.043*WO+.112*WO*WO/1000.-.1323*WO**3/1000000.)*
      1(5.)
       CO=CCO*CO
       GO TO 113
   111 IF (WO.GT.2600.) GO TO 112
C   WO GREATER THAN 14//< BUT LESS THAN 2600.
       CO=WO*(2430.-1.928*WO+.722*WO*WO/1000.-.091*WO**3/1000000.)*
      1(5)
       CO=CCO*CO
       GO TO 113
   112 CONTINUE
C   WO GREATER THAN 2600.
       CO=698.*WO*(5.)
       CO=CCO*CO
   113 CONTINUE
(34) C   CALCULATION OF MACHINERY COST
C   TEST FOR TYPE ENGINE
       IF (NENGU.LE.0) GO TO 6789
C   COSTS FOR GAS TURBINE PLANT
       COSTM=(16.4*SHPREQ+4400000.+1200000.*(ANENG-1.))
       COSTM=CCM*COSTM
       GO TO 9876
```

```
 6789 CONTINUE
      IF (SHPREQ.GT.13000.) GO TO 5678
C  COST FOR STEAM PLANT WITH SHP LESS THAN 13000 SHP
      COSTM=5.*(137.7-(SHPREQ/(75.32+5.92*SHPREQ/100.)))*SHPREQ
      COSTM=CCM*COSTM
      GO TO 9876
 5678 CONTINUE
C  COST FOR STEAM PLANT WITH SHP GREATER THAN 13000 SHP
      COSTM=5.*(SHPREQ/(3.249*SHPREQ/100.-173.95))*SHPREQ
      COSTM=CCM*COSTM
 9876 CONTINUE
(33) C  CALCULATION OF BALAST COST
      COSTB=WB*100.
(42)  COST1=CS+COSTM+CO+COSTB
      IF (COST1) 3001,3001,3002
 3001 COST1=0.001
 3002 CONTINUE
C  CALCULATE ANNUAL OPERATING COST AOC
C  COMPONENTS
C      ADMIN AND MISC COSTS     =ADMIN
C      CREW COSTS               =CC
C      INSURANCE COST           =AIC
C      MAINT AND REPAIR COST    =MRC
C      SUPPLIES AND STOCKS      =SS
C      FUEL COST                =AFC
C      PORT COST                =APC
C  DETERMINATION OF CREW COSTS
(39) C  CREW COST (CC)
      CC=500000.
(41) C  ADMIN AND MISC COSTS
      ADMIN=.2*CC
(37) C  CALCULATE COST OF SUPPLIES AND STOCK
      SS=.1*CC
C  CALCULATE INSURANCE COST (AIC)
C  ASSUME AN INSURANCE RATE
```

```
(40)      ATC=COST1*ATR
(38)  C   DETERMINATION OF MAINT AND REPAIR COST
          MRC=3.47*SHPMAX(J)*(.95)
      C   CALCULATE ANNUAL FUEL COSTS
      C   ASSUME PROCE OF FUEL
(32)      AFC=YFC*PRICE
      C   CALCULATE PORT COSTS PER YEAR (APC)
      C   ASSUME PORT CALL FEES PER ROUND TRIP (PCF)
      C   ASSUME DAILY PORT FEES (DPF)
(31)      APC=TPY*(PCF+TD*DPF)
      C   TOTAL
(43)      AOC=(ADMIN+CC+AIC+MRC+SS+AFC+APC)
      C   CALCULATION OF INITIAL CASH FLOW UPON PURCHASE (CASH1)
      C   ASSUMED VALUES FOR
      C       PERCENT FINANCED    =PF
      C       SUBSIDY RATE        =SUBSR
          SUBSID=SUBSR*COST1
          FINAN=PF*(COST1-SUBSID)
      C   EFFECTIVE INVESTMENT TAX CREDIT = TCRED
          TCRED=(COST1-SUBSID)*AITC
      C   OWNERS OUT OF POCKET BUILDING COST
(45)      CASH1=SUBSID+FINAN+TCRED-COST1
      C   CALCULATION OF ANNUAL LOAN PAYMENT FACTOR
      C   ASSUME
      C       INTEREST RATE       =RATE
      C       PERIOD=NN
      C     ' PAYMENT FACTOR-PAYMTF
      C   REQUIRE NN LARGER THAN THREE FOR EQUATIONS TO HOLD
          MM=NN-3
          CONST=1.+RATE
          OLD=1.
          SUM=1.
          DO 41 J=1,MM
          ANEW=CONST*OLD
          SUM=SUM+ANEW
```

```
      OLD=ANEW
   41 CONTINUE
      CONST1=CONST*OLD
      ANUMER=CONST*CONST*CONST1
      DENOM=SUM+CONST1*(CONST+1.)
      PAYMTF=ANUMER/DENOM
C  CALCULATE ANNUAL CASH FLOW ON LOAN FOR ANNUAL PAYMENT (PAYMT)
C     CONSTANT PAYMENT   =PAYMT
(45')  PAYMT=PAYMTF*FINAN
C  CALCULATION OF DEPRECIATION FOR TAX CALCULATION
C  ASSUME
C     METHOD                =STREIGHT LINE
C     SALVAGE VALUE         =SV
C     NUMBER OF YEARS       =NN
      ANN=NN
(45')  DEPR=(COST1-SV-SUBSID)/ANN
C  CALCULATION OF ANNUAL CASH FLOW (CASHA)
C  DEFINE VARIABLES
C     ANNUAL REVENUE           =R
C     ANNUAL OPERATING COST    =AOC (BEFORE TAX AND LOAN PAYMENTS)
C     ANNUAL PAYMENT ON LOAN   =PAYMT
C     ANNUAL TAX PAYMENT       =TRAYMT
C  ASSUME CORPORATE TAX RATE VCTR
      GROSS=R-AOC-PAYMT
      DEPLES=GROSS-DEPR
      IF (DEPLES) 11,11,22
   11 CONTINUE
      DEPLES=0.
   22 CONTINUE
      TRAYMT=CTR*DEPLES
(46)  CASHA=GROSS-TRAYMT
C  CALCULATION OF NET PRESENT VALUE (NPV) FROM CASH FLOWS AFTER TAX
C  ASSUMED VALUES FOR
C     TIME VALUE OF MONEY      =DF(DISCOUNT FACTOR)
C     NUMBER OF YEARS          =NN
```

```
   C       SALVAGE VALUE              =SV
           CONST=(1.+DF)**NN
           ANUMER=CONST-1.
           DENOM=CONST*DF
(48) C   NET PRESENT VALUE = ANPV
           ANPV=CASH1+CASHA*(ANUMER/DENOM)+SV/CONST
(49) C   CAPITAL RECOVERY FACTOR=CRF
           CRF=CASHA/(FINAN+(-CASH1))
(47) C  REQUIRED FREIGHT = RFR (DOLLARS PER TON)
           RFR=(AOC+PAYMT+DEPR)/(WP+.001)/TPY
   C   OPTION TO DETERMINE OBJECTIVE SURFACE
           GO TO (441,442,443), IOBJ
      441  VAL=-ANPV*(1.D-06)
           GO TO 444
      442  VAL=-CRF*1000.
           GO TO 444
      443  VAL=RFR
      444  CONTINUE
           RETURN
           END
```

```
      SUBROUTINE SHPRO
      DOUBLE PRECISION DUM1(93), DUM2(100), DUM3(100,100), VAL,
     1DISPL, LENGT, BEAM, DRAFT, DEPTH, CP, VELOC
      REAL LENGTM,LDR,LBP,LF,LP,LM,KGO,KGS,KGM,KGX,KGB,KB,KGF,
     1MPC
      COMMON/SHP/ CP(6210), CPS(10), CTS(10), CFS(10), ETAD(10),
     1PE(10), R(10), VL(10), PS(10), UOR(10)
      COMMON/SHAPE/DISPL,LENGT,BEAM,DRAFT,DEPTH,CP,VELOC,DUM1,
     1DUM2,DUM3,N,M,MN,NP1,NM1
      COMMON /PUTIN/ GNU,GAMMA,NVEL,DCF,NER
      COMMON/OVAR/LDR,VLR,RDR,LBR,VOL,CV,CB,CM,SHPREQ
      COMMON/PARAM/PC,F,DPP,SHPM,TD,WW,HP,WC,ELENGT,EWIDTH,EDEPTH,MD,
     1PCF,DPF,FP,PRICE,ATP,AVAIL,IPOJ
      XLWL=LENGT
      XLBP=LENGT
      UOR(1)=VELOC
      UOR(1)=UOR(1)*1.688889
      VL(1)=VLR
      ETAD(1)=PC
      RTP=RBD
      RO=1.9903
      US=0.
      IF(CP.LT.0.48.OR.CP.GT.0.70) GO TO 1006
      IF(RTP.LT.2.25.OR.RTP.GT.3.75) GO TO 1006
      IF(CV.GE..001.AND.CV.LE..006) GO TO 1007
 1006 CONTINUE
      DO 1008 NER=1,NVEL
      CTS(NER)=0.0
      CFS(NER)=0.0
      R(NER)=0.0
      PE(NER)=0.0
      CPS(NER)=0.0
 1008 PS(NER)=180000.
      GO TO 121
 1007 IF(US.GT.0.0) GO TO 110
```

```
C     COMPUTE WETTED SURFACE
      CS1=15.086
      CS2=15.046
      CS3=15.115
      CS4=15.293
      IF(BTR-2.75) 6,7,8
 6    ABTR=2.75-BTR
      CS=CS2-((CS2-CS1)*ABTR)/0.5
      GO TO 9
 7    CS=CS2
      GO TO 9
 8    IF(BTR-3.25)66,77,88
 66   ABTR=3.25-BTR
      CS=CS3-((CS3-CS2)*ABTR)/0.5
      GO TO 9
 77   CS=CS3
      GO TO 9
 88   ABTR=3.75-BTR
      CS=CS4-((CS4-CS3)*ABTR)/0.5
 9    WS=CS*SQRT((VOL/35.)*XLBP)
 110  VLMIN=.5
      VLMAX=1.2
      DO 120 NFR=1,NVEL
      VL(NFR)=UOR(NFR)/(1.688889*SQRT(XLWL))
      IF(VL(NFR).GE.VLMIN.AND.VL(NFR).LE.VLMAX) GO TO 1002
```

```
      CTS(NFR)=0.0
      CFS(NFR)=0.0
      R(NFR)=0.0
      PE(NFR)=0.0
      CPS(NFR)=0.0
      PS(NFR)=130000.
      GO TO 120
 1002 CALL RESIS(DCPS)
      CPS(NFR)=DCPS
      RES=UOR(NFR)*XLWL/GNU
      CFS(NFR)=0.075/(((ALOG(RES)/2.3025851)-2.0)**2)
      DO 1003 K=1,50
      BOGUS=CFS(NFR)
      CFS(NFR)=(2.3025851/(4.132*ALOG(RES*CFS(NFR))))**2
      IF(ABS(BOGUS-CFS(NFR))-5.0E-07) 1004,1004,1003
 1003 CONTINUE
      WRITE(6,5) UOR(NFR)
 5    FORMAT('  SCHOENHER NO CONVERGE.  UOR=',F6.3)
 1004 CTS(NFR)=CFS(NFR)+CPS(NFR)+DCF
      R(NFR)=.5*RO*WS*UOR(NFR)**2*CTS(NFR)
C   ACCOUNT FOR APPENDAGE DRAG

      PE(NFR)=R(NFR)*UOR(NFR)/550.
      PS(NFR)=PE(NFR)/ETAD(NFR)
 120  CONTINUE
  121 SHPREQ=PS(1)
      RETURN
      END
```

```
      SUBROUTINE RESIS(DCRS)
      DOUBLE PRECISION DUM1(93), DUM2(100), DUM3(100,100), VAL,
     1DISPL, LENGT, BEAM, DRAFT, DEPTH, CP, VELOC
      REAL LENGTM,LDR,LBR,LF,LP,LM,KGO,KGS,KGM,KGX,KGB,KB,KGF,
     1MRC
      COMMON/SHP/ CP(6210), CPS(10), CTS(10), CFS(10), FTAD(10),
     1PE(10), R(10), VL(10), RS(10), HOR(10)
      COMMON/SHAPE/DISPL,LENGT,BEAM,DRAFT,DEPTH,CP,VELOC,DUM1,
     1DUM2,DUM3,N,M,NU,NP1,N41
      COMMON/PUTIN/GNU,GAMMA,NVEL,DCF,NFR
      COMMON/OVAR/LDR,VLR,BDR,LBR,VOL,CV,CB,CM,SHPREQ
      TYPEF(II,IJ,KK)=23*15*(II-1)+15*(IJ-1)+KK
      TYPREF(II,IJ,KK)=1035+TYPEF(II,IJ,KK)
C     COMPUTATION OF RESIDUAL RESISTANCE
      VL(NFR)=VLR
      RTR=BDR
      CVV=CV*1000.0
      IF(CVV-2.0)89,90,90
   89 MMM=0
      CVD=CVV-1.0
      GO TO 4
   90 IF(CVV-3.0)91,92,92
   91 MMM=1
      CVD=CVV-2.0
      GO TO 4
   92 IF(CVV-4.0)93,94,94
   93 MMM=2
      CVD=CVV-3.0
      GO TO 4
   94 IF(CVV-5.0)95,96,96
   95 MMM=3
      CVD=CVV-4.0
      GO TO 4
   96 MMM=4
      CVD=CVV-5.0
```

```
4     IF(RT2/3.0-1.0)7,8,8
7     I=1
      GO TO 9
8     I=2
9     LL=100.0*CP
      ALL=LL
      AL=100.*CP-ALL
      IF(AL-.5)10,11,11
10    J=LL-47
      GO TO 12
11    J=LL-46
12    K=20.*(VL(NER)+.05)-9.
      L=IXREF(I,J,K)
      L=L+1035*MMM
      AA=CR(L)
      L=IXREF(I,J,K)
      L=L+1035*MMM
      BB=CR(L)
      L=IXREF(I+1,J,K)
      L=L+1035*MMM
      CC=CR(L)
      L=IXREF(I+1,J,K)
      L=L+1035*MMM
      DD=CR(L)
      L=IXREF(I,J,K-1)
      L=L+1035*MMM
      EE=CR(L)
      L=IXREF(I,J,K-1)
      L=L+1035*MMM
      FF=CR(L)
```

```
      L=IXPFF(I+1,J,K-1)
      L=L+1035*MM
      GG=CP(L)
      L=IYPFF(I+1,J,K-1)
      L=L+1035*MY
      HH=CP(L)
      ABB=(BB-AA)*CVD+AA
      ACC=(DD-CC)*CVD+CC
      ADD=(EE-FF)*CVD+FF
      AFF=(HH-GG)*CVD+GG
      IF(BTC-3.0)23,24,24
   23 BTPD=BTP-2.25
      GO TO 25
   24 BTPD=BTP-3.00
   25 BAA=(ACC-ABB)*BTPD/0.75+ABB
      BBB=(AFF-ADD)*BTPD/0.75+ADD
      AK=K
      VLD=0.45+AK*0.05
      VLD=VLD-VL(IFD)
      DCBS=(BAA-(BAA-BBB)*VLD/0.05)/1000.
      RETURN
      END
```

Thesis 153603
F623 Fortson
Application of the sequential unconstrained minimization technique in a systematic containership design.